Calorimetry R&D for an EIC Detector

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RHIC/AGS User's Meeting

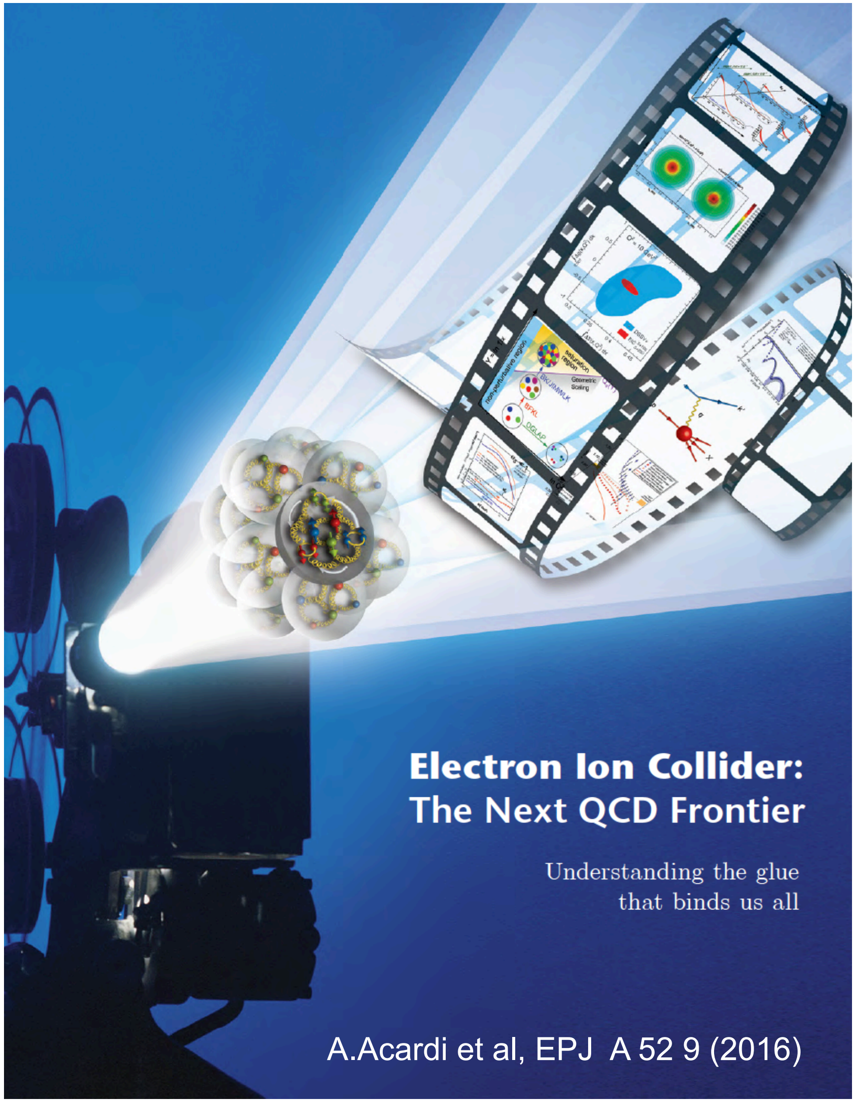
BNL June,5 2019

Outline

- **EIC Project and the Detector R&D Program**
- **Electromagnetic Calorimetry R&D**
  - W/SciFi sampling design: from first prototypes to sPHENIX
  - W/Cu/SciTile shashlik
  - “Traditional“ PWO crystals ...
  - ... and new ceramic glass materials for EIC calorimetry
- **Hadron Calorimetry R&D**
  - Pb(Fe)/SciTile sandwich design: present status & future opportunities
  - Other options
- **SiPM radiation damage studies**
- **Summary**

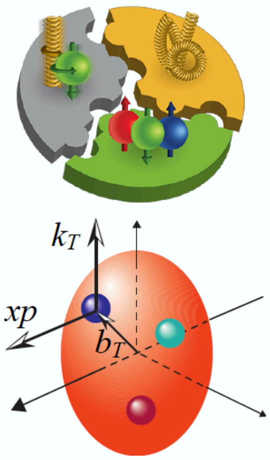
EIC Physics

Precision study of quark and gluon dynamics inside nucleon and nuclei

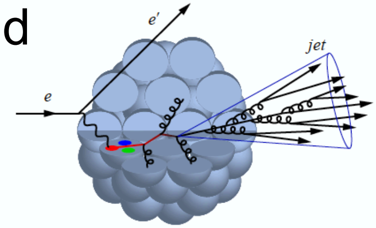


Key questions:

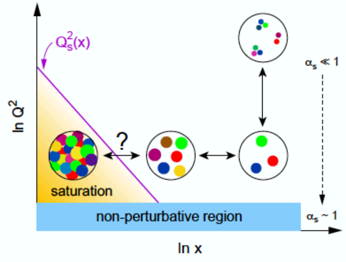
- How are the sea quarks and gluons, and their spins, distributed in space and momentum inside the nucleon?



- How does the nuclear environment affect the distribution of quarks and gluons and their interactions in nuclei?

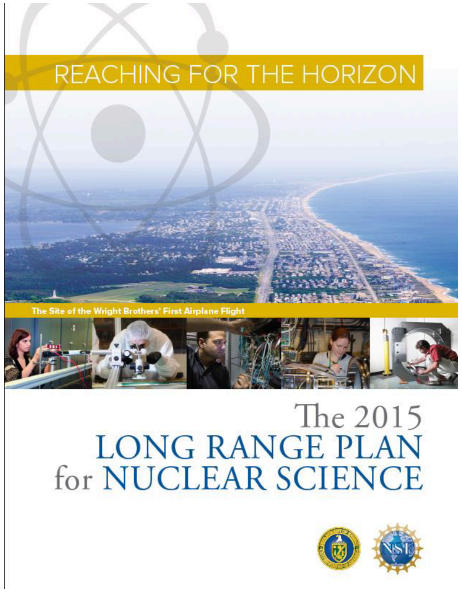


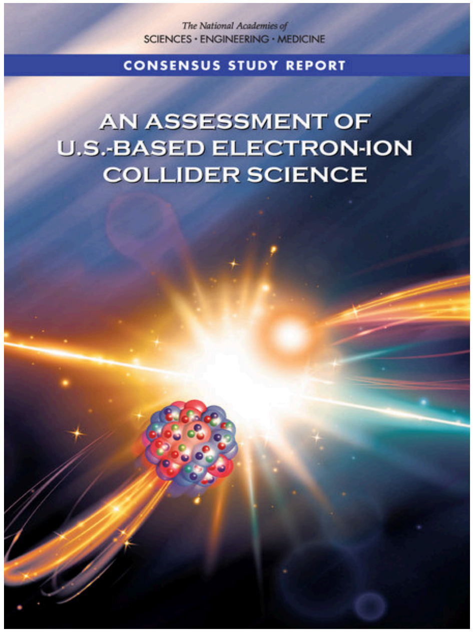
- Where does the saturation of gluon densities set in? Does this saturation produce matter with universal properties?



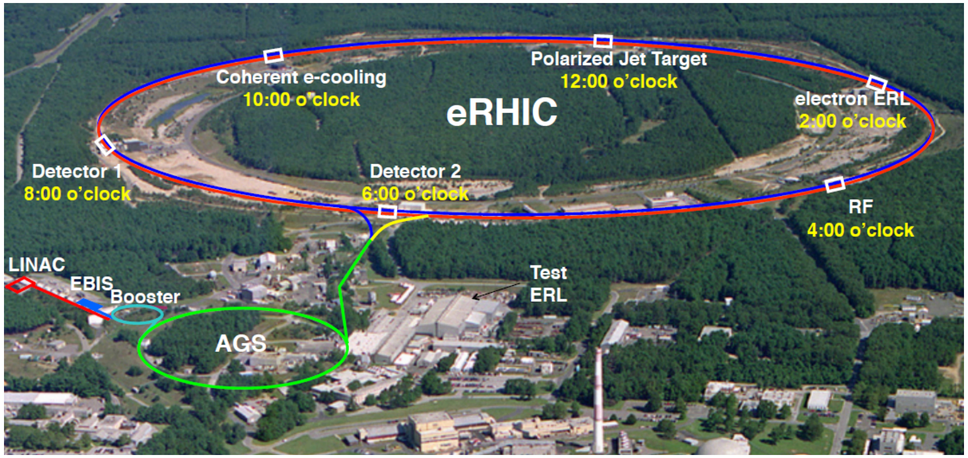
Timelines

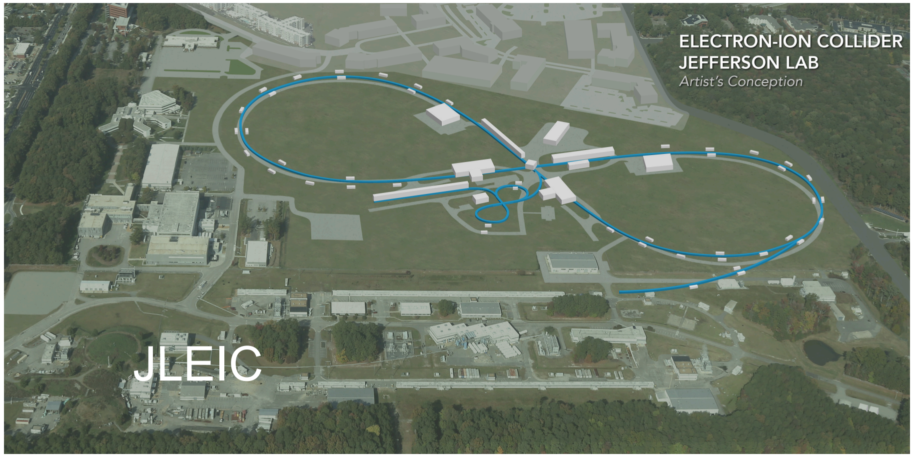
- **2015 NSAC (NP) Long-Range Plan:**
  - “We recommend a high-energy high-luminosity polarized EIC as the highest priority for new facility construction.”
- **2018 NAS review:**
  - “The committee finds that the science that can be addressed by an EIC is compelling, fundamental and timely.”
- **President’s budget request for FY2020:**
  - Critical Decision-0, Approve Mission Need, is planned for FY2019

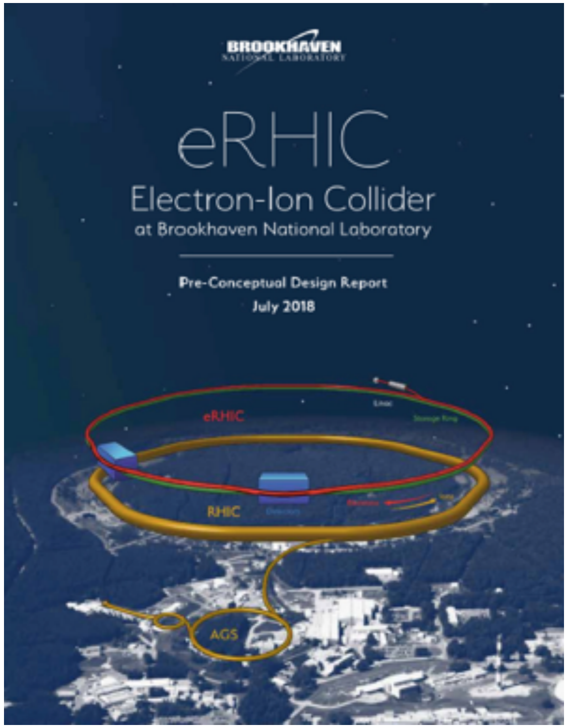




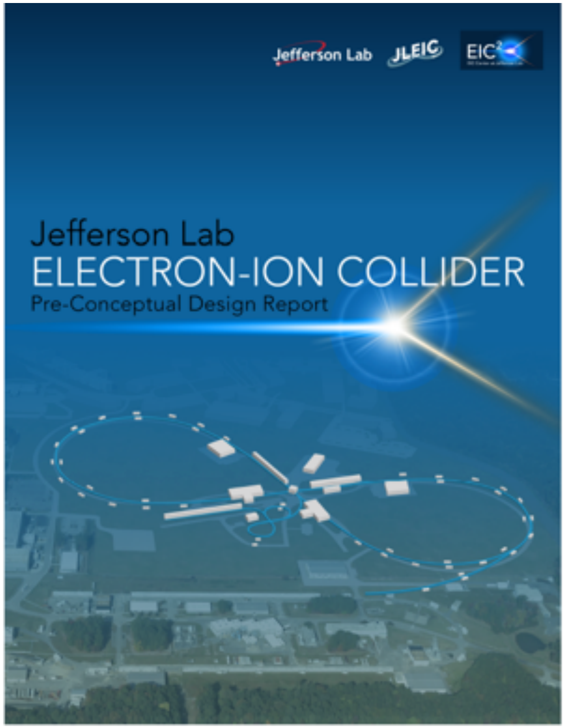
Machine requirements & EIC realization





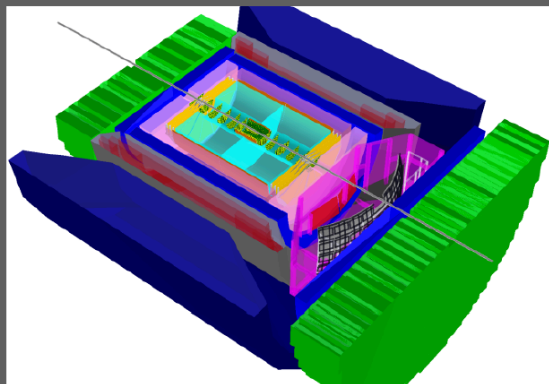


- Wide kinematic range: √s from ~20 to 100 GeV, upgradable to 140 GeV
- Luminosity ~$10^{33\text{-}34}$ $cm^{-2}s^{-1}$
- Polarized protons, electrons and light ions
- Heavy ion beams up to U

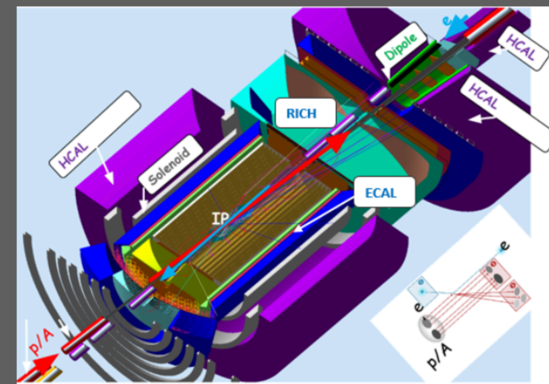


EIC detector concepts

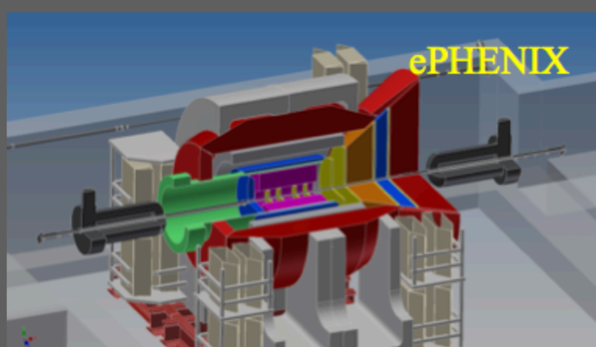
Brookhaven concept: BEAST



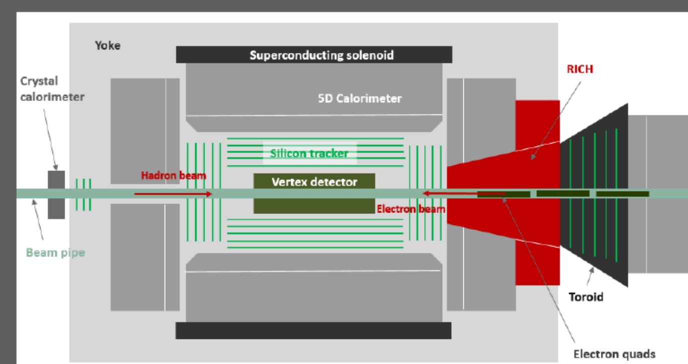
Jefferson lab concept: JLEIC



sPhenix → ePhenix



Argonne concept: TOPSiDE



EIC Detector Concepts

- **General observations (e.g. @ Temple UG meeting in Nov'2017):**
  - Community wants ***two*** general-purpose detectors
  - Nothing is cast in stone; several options evolved already

- **Common features:**
  - Compact design
  - (Almost) 4π hermetic acceptance in tracking/calorimetry/PID
  - Vertex + central + forward/backward + far forward tracker layout
  - Low material budget in the tracker volume
  - Strong central solenoid field
  - Moderate momentum resolution (~1% level)
  - Moderate EmCal and HCal energy resolution

Generic Detector R&D for an EIC

- In January 2011 BNL, in association with JLab and the DOE Office of NP, announced **a generic detector R&D program** to address the scientific requirements for measurements at a future EIC

Goals:

- Enable successful design and timely implementation of an EIC experimental program
  - Quantify the key physics measurements that drive instrumentation requirements
  - Develop instrumentation solutions that meet realistic cost expectations
- Stimulate the formation of user collaborations to design and build experiments

Program coordinator 2011-2014 : T. Ludlam
2014-present: T. Ullrich

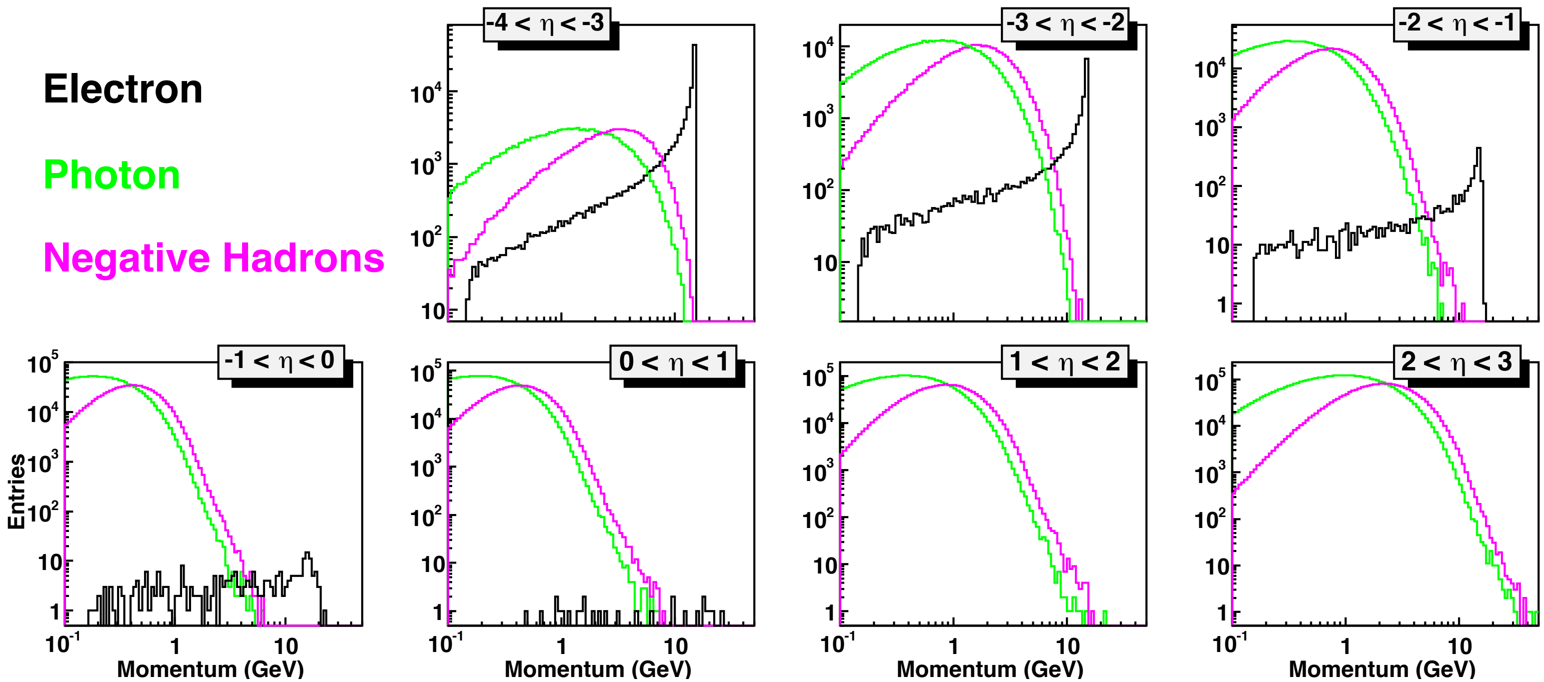
EIC R&D program: tracking projects

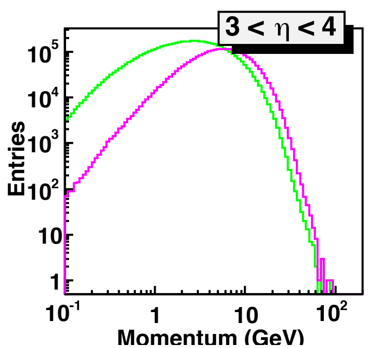
Project	Main focus
eRD1	Calorimeter Consortium
eRD6	Tracking & PID
eRD14	PID Consortium
eRD16	Forward/Backward Tracking with MAPS detectors
eRD17	BeAGLE event generator
eRD18	Precision Central Silicon Tracking & Vertexing
eRD20	Software Consortium
eRD21	Background studies
eRD22	GEM-TRD
eRD23	Streaming readout

Electromagnetic Calorimetry

Relative electron/photon/e$^-$ yields

15x250 GeV configuration; particle yields versus momentum in the 4 < η < 4 range:





γ suppression:
the same η coverage for
tracking & Ecal

h$^-$ suppression through E/p
-3.5<η<-1: 10:1 to 10^3:1
−1<η <1: 10^4:1

EM calorimetry: use case & requirements

Regions and Physics Goals	Calorimeter Design
Lepton/backward: EM Cal ○ Resolution driven by need to determine (x, Q^2) kinematics from scattered electron measurement ○ Prefer 1.5%/√E + 0.5%	Inner EM Cal for for η < -2: ➢ Good resolution in angle to order 1 degree to distinguish between clusters ➢ Energy resolution to order (1.0-1.5 %/√E+0.5%) for measurements of the cluster energy ➢ Ability to withstand radiation down to at least 2-3 degree with respect to the beam line. Outer EM Cal for -2 < η < -1: ➢ Energy resolution to 7%/√E ➢ Compact readout without degrading energy resolution ➢ Readout segmentation depending on angle
Ion/forward: EM Cal ○ Resolution driven by deep exclusive measurement energy resolution with photon and neutral pion ○ Need to separate single-photon from two-photon events ○ Prefer 6-7%/√E and position resolution < 3 mm	
Barrel/mid: EM Cal ○ Resolution driven by need to measure photons from SIDIS and DES in range 0.5-5 GeV ○ To ensure reconstruction of neutral pion mass need: 8%/√E +1.5% (prefer 1%)	Barrel EM Cal: ➢ Compact design as space is limited ➢ Energy resolution of order 8%/√E +1.5%, and likely better Hadron endcap EM Cal: ➢ EM energy resolution to < (12%/√E + 1%)

T.Horn, 07/26/18 EIC R&D Meeting: the most complete “consensus” table at this time

Overall remarks

- **These “requirements” are a combination of**
  - Limited amount of modeling studies
  - Past experience
  - Present and/or near future state of the (calorimetry) art
  - Progress within the EIC Detector R&D Program
  - Common sense & educated guesses
  - Trade-offs coming from budget constraints

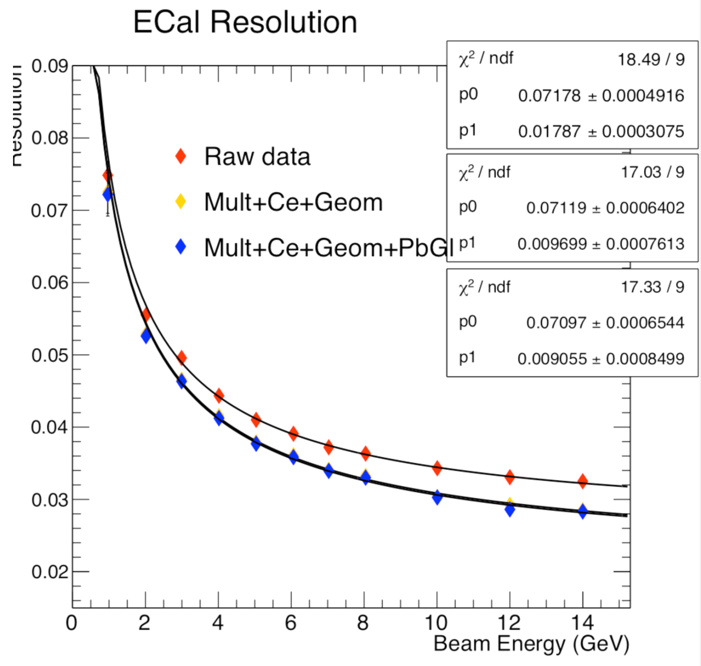
-> We believe they are good enough as a guidance and as a starting point for various types of physics analyses

-> If your estimates and/or modeling results show these requirements can be further refined, you are more than welcome to contribute!

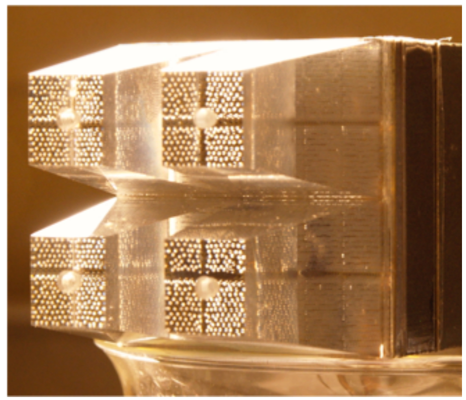
See also EIC Detector R&D Handbook: http://www.eicug.org/web/content/detector-rd

W/SciFi EIC calorimeter R&D: early days

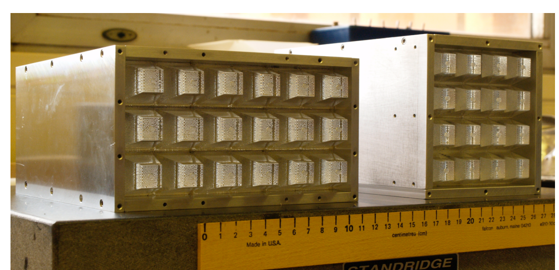
- Scintillating fibers embedded in a composite absorber (tungsten power + epoxy)
- Round and square fibers tested



Detector	Fibers SCSF 78	Absorber
"Old" High sampling frequency	Round, 0.4mm	75% W 25% Sn
"Square" High sampling fraction	Square, 0.59 x 0.59 mm²	100% W

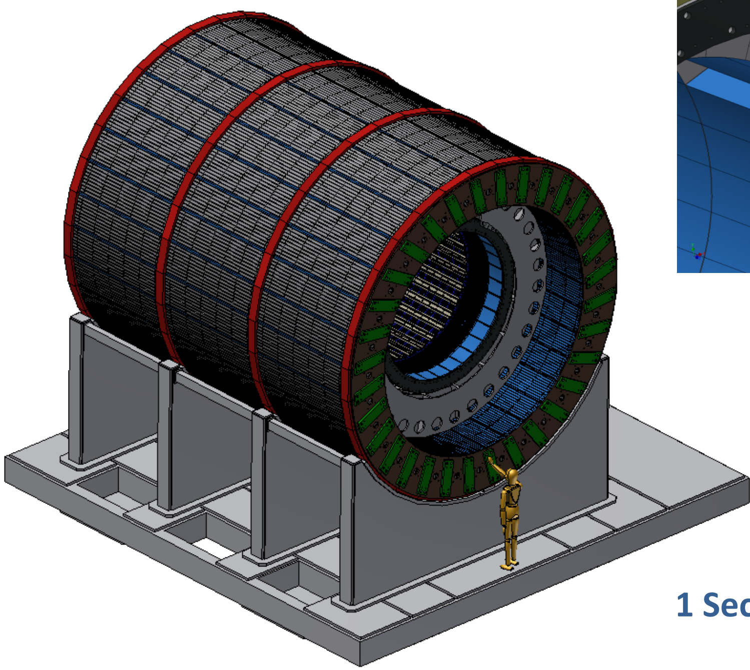


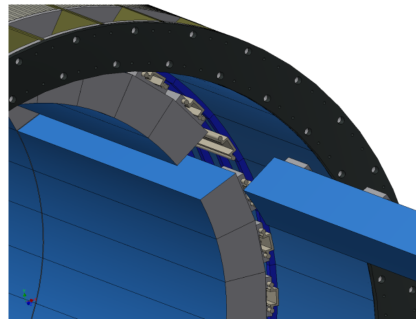
- Several test beam campaigns in 2012 .. 2016
- Achieve 7-12%/√E (variable by design), with ~1% constant term at 10°, ~3% at 4°
- PMT and SiPM implementations
- Beam installation at RHIC in 2017



W/SciFi design: sPHENIX implementation

2(±η) x 32 (ϕ) = 64 Sectors

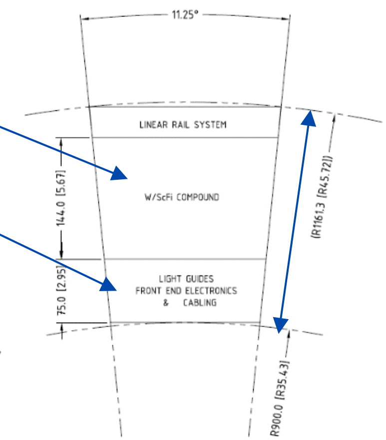


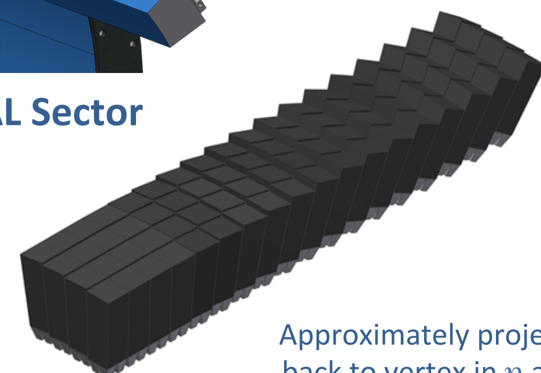


EMCAL Sector

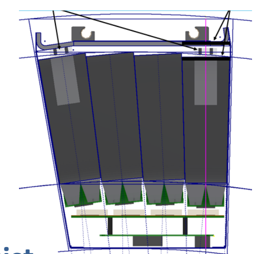
~14 cm absorber (η=0)

7.5 cm readout





Approximately projective back to vertex in η and ϕ



1 Sector = 72 Blocks
= 288 towers

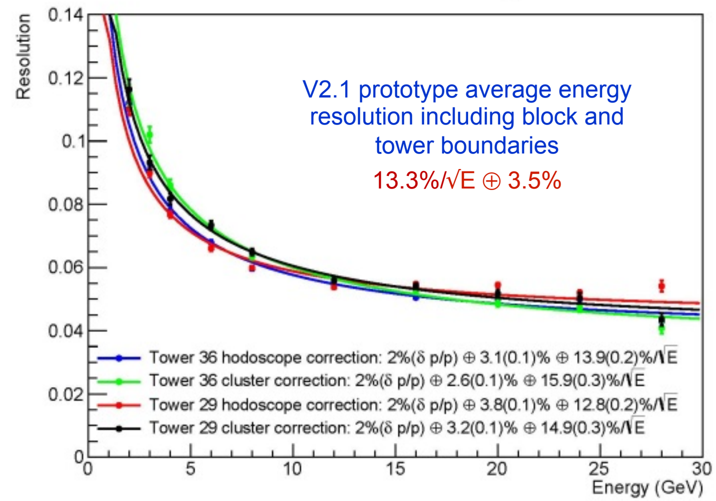
Module = Block/Reflector/Light Guides/SiPMs

Blocks consist of 2x2 towers

- Coverage: ± 0.85 in η, 2π in ϕ
- Segmentation: $\Delta\eta \times \Delta\varphi \approx 0.025 \times 0.025$
- Readout channels (towers): 72x256 = 18432
- Energy Resolution: $\sigma_E/E < 16\%/\sqrt{E} \oplus 5\%$
- Provide an e/h separation > 100:1 at 4 GeV
- Approximately projective in η and ϕ
- Compact, works inside 1.4T magnetic field and reduces cost of HCAL

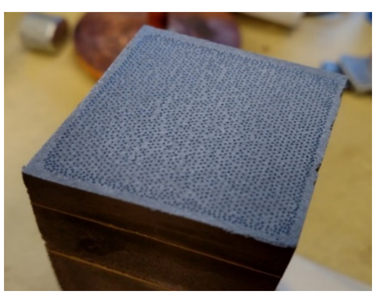
W/SciFi design: sPHENIX implementation

- **The EMCAL has undergone 4 rounds of prototyping and beam tests at Fermilab and is in a very mature stage.**
- **Results have shown that the detector can meet the requirements for the sPHENIX physics program.**
- **A detailed engineering design has been developed for the complete detector.**

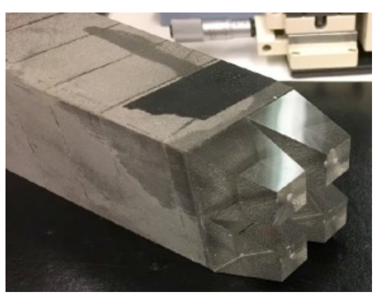


- Construction of the first pre-production prototype sector (Sector 0) is under way. All blocks have been produced at UIUC and are being installed in the sector at BNL.

Readout End Scintillating Fibers



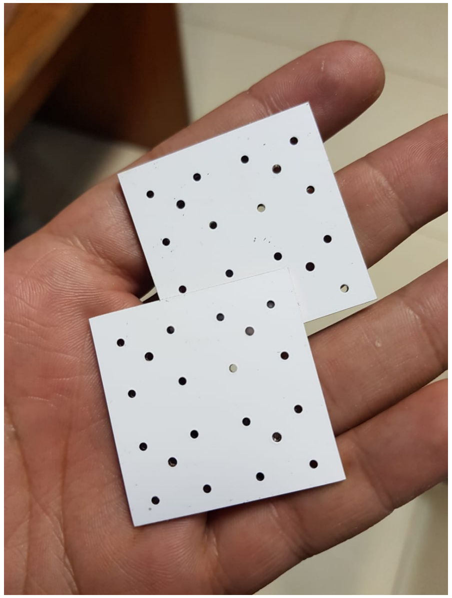
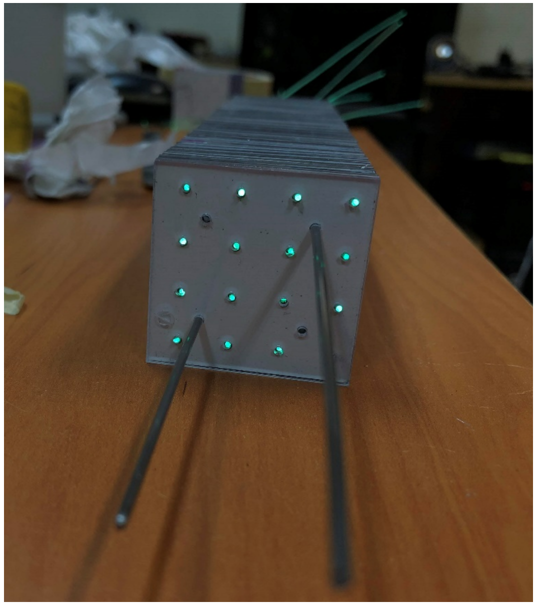
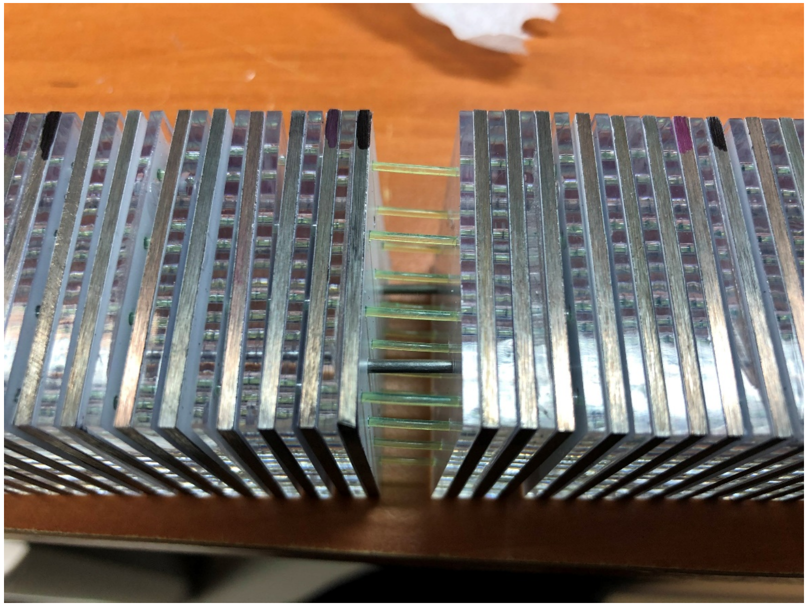
Light Guides
4 towers/block



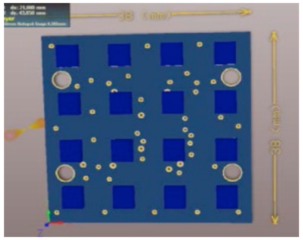
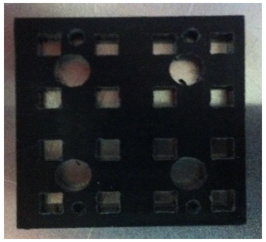
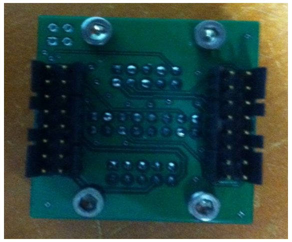
W/SciFi Absorber Block

Blocks installed in Sector 0 at BNL

W/Cu/SciTile shashlik calorimeter

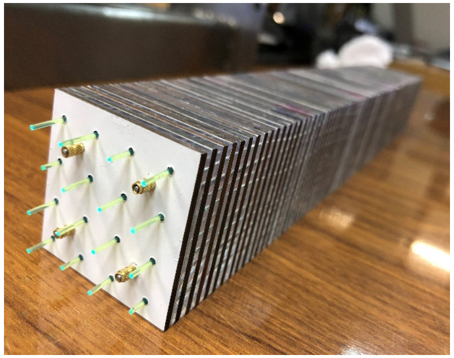
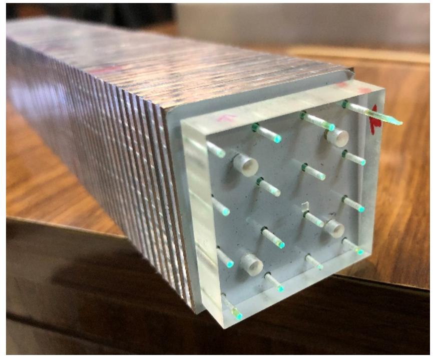
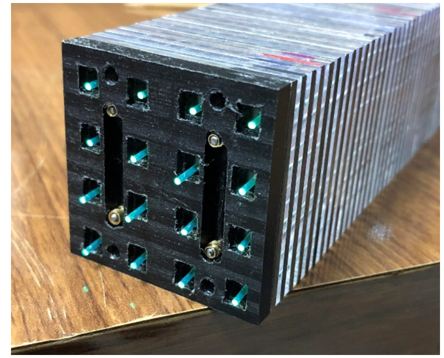
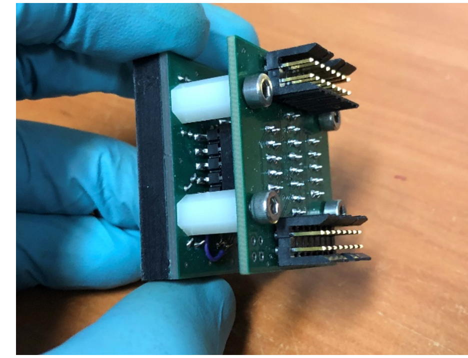




- Use W80/Cu20 alloy as absorber
- Read out each WLS fiber with an individual SiPM

- A viable alternative solution to W/SciFi calorimeter ...
- ... potentially with a better light collection uniformity in a compact design

W/Cu/SciTile shashlik calorimeter

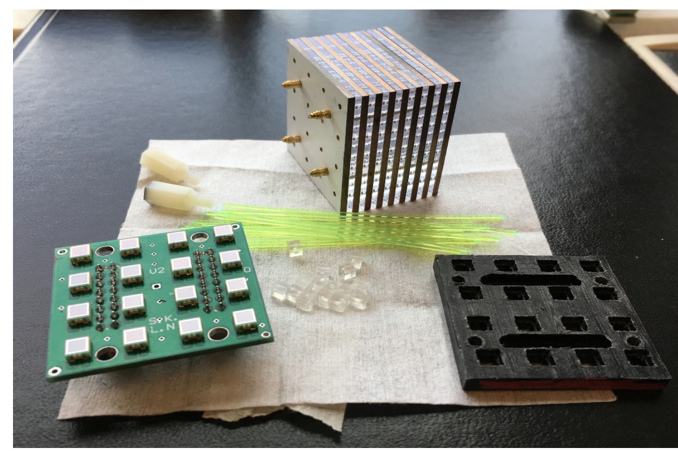





Stack of seventy 38 x 38 x 1.5 mm W80Cu20 absorber plates and 1.5 mm scintillator plates

Readout consists of 16 WLS fibers each read out with its own 3x3mm^2 SiPM

- First module completed at UTFSM
- LED and cosmic tests are ongoing (light yield, uniformity, timing)

- A short stack is shipped to BNL for light collection uniformity studies

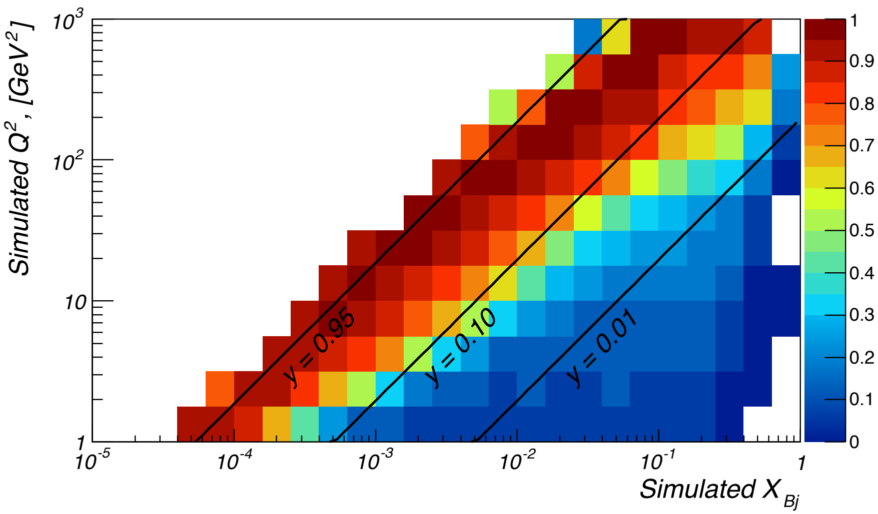


Scattered electron kinematics reconstruction

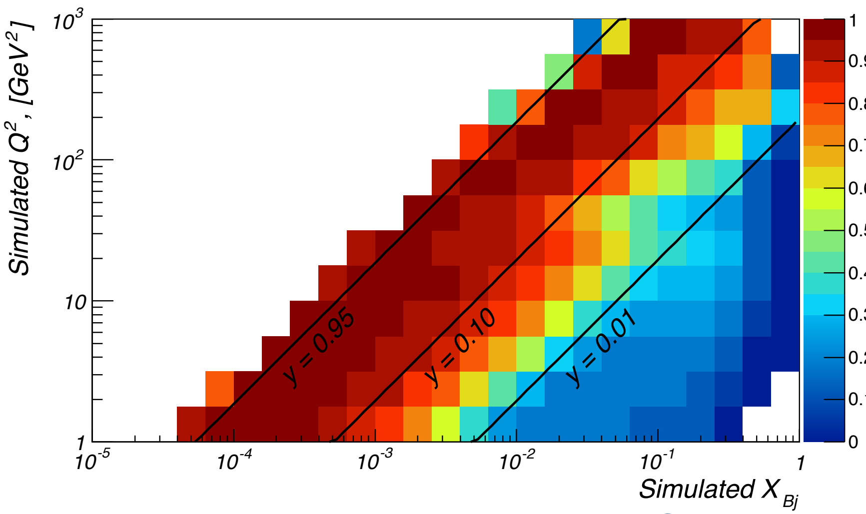
$$Purity = \frac{N_{gen} - N_{out}}{N_{gen} - N_{out} + N_{in}}$$

- Describes migration between kinematic bins
- Important to keep it close to 1.0 for successful unfolding

- A possible way to increase ***y*** range: use e/m calorimeter in addition to tracking
  - ~2%/√E energy resolution (and ~0 constant term) for $\eta < -2$ (PWO crystals)
  - ~7%/√E energy resolution for $-2 < \eta < 1$ (W/SciFi sampling towers)



Lepton tracking only



Lepton tracking + EmCal

- Apparently, the high-resolution crystal EmCal at very backward rapidities can help increasing the available ***y*** range ...
- ... but only if it has a very small constant term and is “radiation hard”

Crystal Calorimetry

- PbWO calorimeter option for this role, extensively used for high precision calorimetry (CMS, JLab, PANDA…) because of its excellent energy and time resolutions and its radiation hardness

- BTCP (Russia) produced high quality crystals in the past but out of business

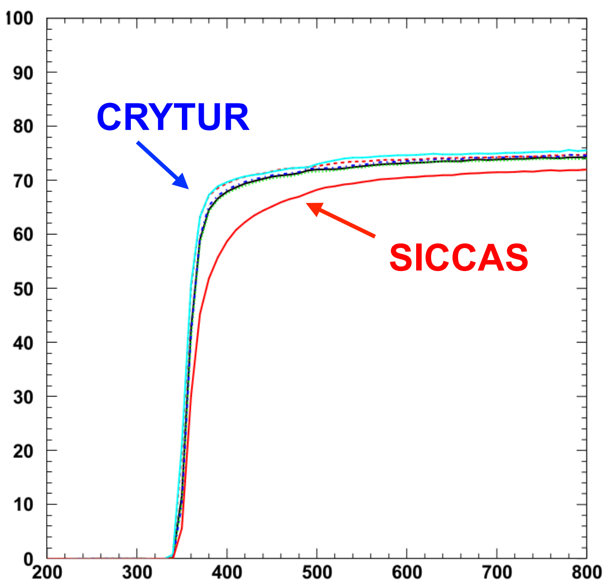
- SICCAS (China) has difficulties maintaining good crystal quality
- Collaborative effort with PANDA to qualify CRYTUR (Czech Republic)

Crystal characterization

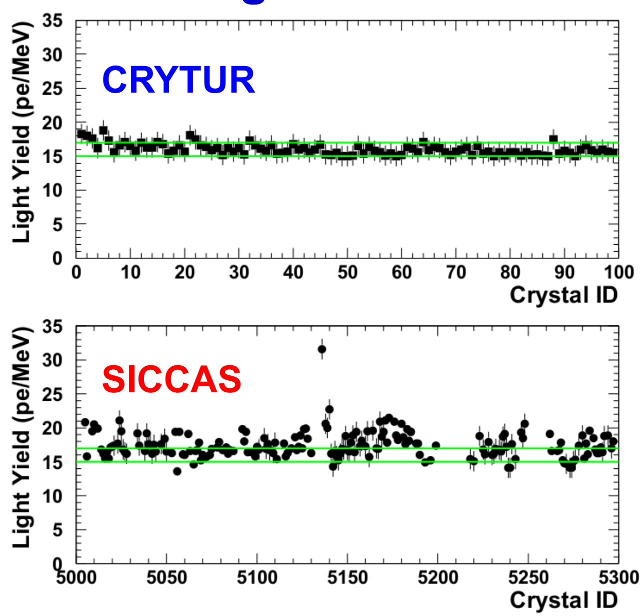
- **SICCAS**: 160/460 SICCAS 2017 crystals rejected due to major mechanical defects – an additional 52 pieces fail specifications

- **CRYTUR**: Strict quality control procedures – so far 100% of crystals accepted
  - Limited capacity, ~200 pc/year – 100 crystals in 2018, maxed out due to PANDA order

Transmittance



Light Yield

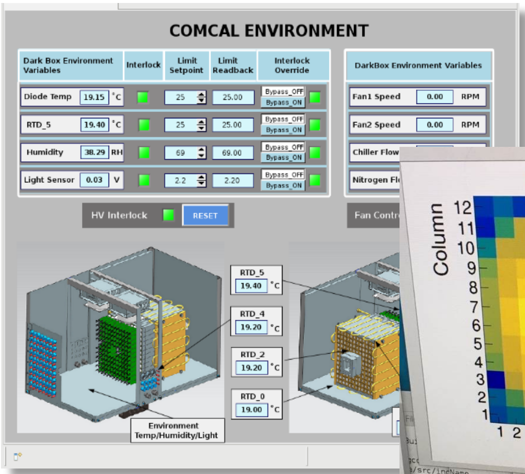


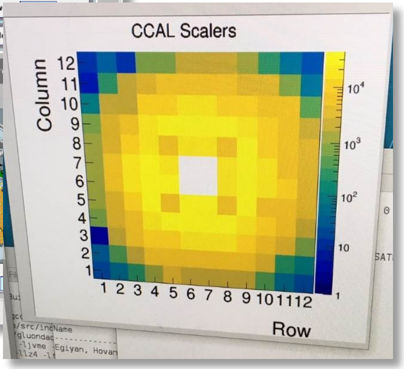
Radiation Hardness

CRYTUR crystal quality superior to SICCAS – measurements important for placement in detector, e.g. SICCAS away from high radiation zones

Crystal calorimetry: test beam campaign

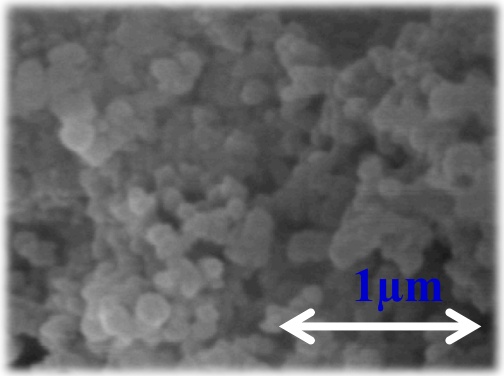
- ❑ Designed and constructed a 12 x 12 prototype of geometry representative of NPS and EIC EMCal
  - ➢ 144 scintillator blocks of dimensions 2.05cm x 2.05 cm x 20cm with PMT readout and custom HV divider
  - ➢ Rectangular geometry most suitable
  - ➢ Developed analysis software and slow controls for monitoring temperature etc.
- ❑ Installed and commissioned in Hall D in fall 2018
  - ➢ Photon beam energies between 1 -10 GeV
    - ○ Measured with Hall D tagging system – resolution ~0.1%
  - ➢ Preliminary results indicate prototype energy resolution ~2% (1.4-1.6%) for 4.2 (10) GeV photons – improvement anticipated





New materials for EIC calorimetry

- **Ceramic glass as active calorimeter material:**
  - More cost effective that PWO
  - Easier to manufacture
  - Better optical properties (?)
  - Technology: glass production combined with successive thermal annealing (800 – 900^oC)



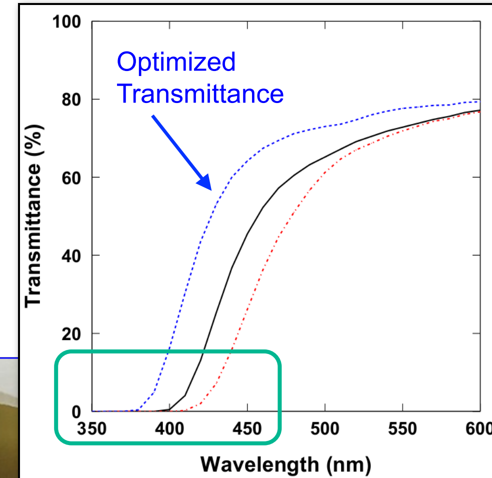
SEM image of recrystallized $BaO*2SiO_2$ at 950^oC

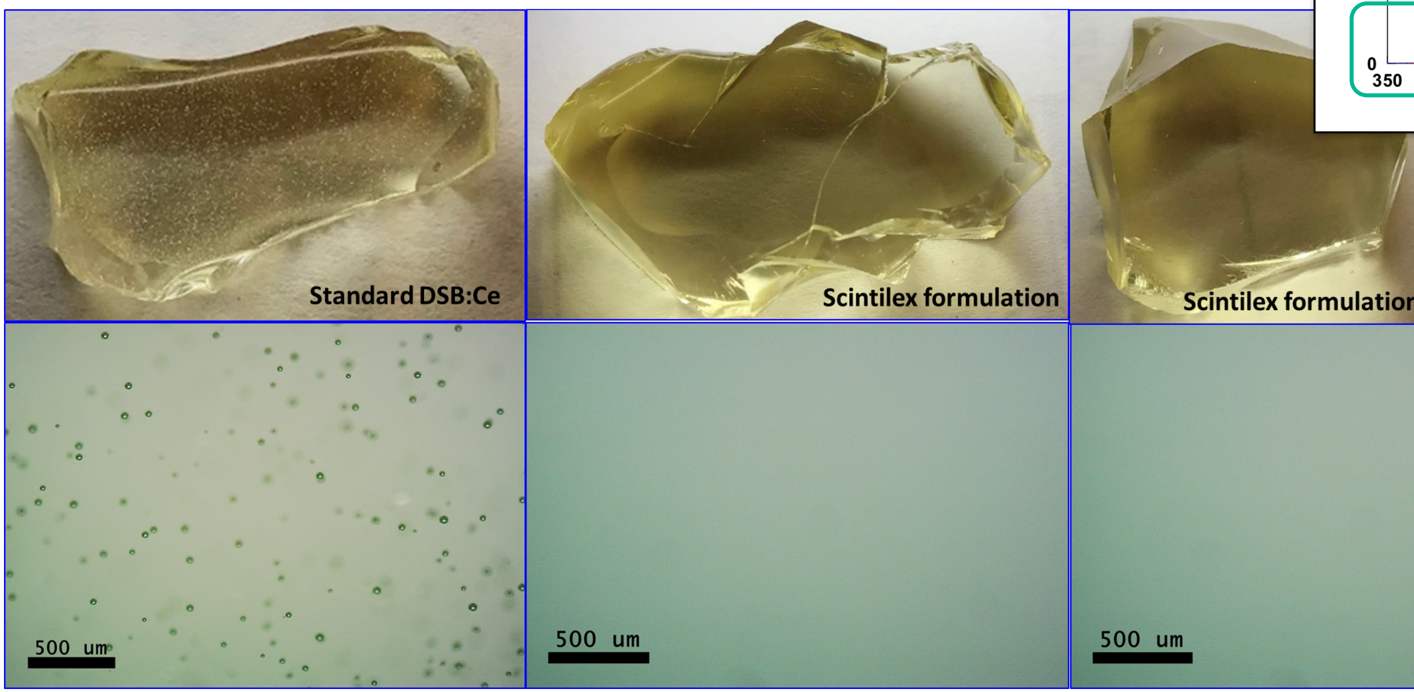
Material/ Parameter	Density (g/cm^3)	Rad. Length (cm)	Moliere Radius (cm)	Interact Length (cm)	Refr. Index	Emission peak	Decay time (ns)	Light Yield (γ/MeV)	Rad. Hard. (krad)	Radiation type	Z_{Eff}
(PWO)$PbWO_4$	8.30	0.89 0.92	2.00	20.7 18.0	2.20	560 420	50 10	40 240	>1000	.90 scint. .10 Č	75.6
($BaO*2SiO_2$):Ce glass	3.7	3.6	2-3	~20		440, 460	22 72 450	>100	10 *(no tests >10krad yet)*	Scint.	51
($BaO*2SiO_2$):Ce glass loaded with Gd	4.7-5.4	2.2		~20		440, 460	50 86-120 330-400	>100	10 *(no tests >10krad yet)*	Scint.	58

Also: ($BaO*2SiO_2$):Ce shows no temperature dependence

Glass ceramic: optical property tuning

- Uniformity remains a concern – manufacturing process requires optimization – progress with new method at CUA/VSL/Scintilex





Sample made at CUA/VSL based on previous DSB:Ce work

Samples made at CUA/VSL/Scintilex with our new method

Hadronic calorimetry

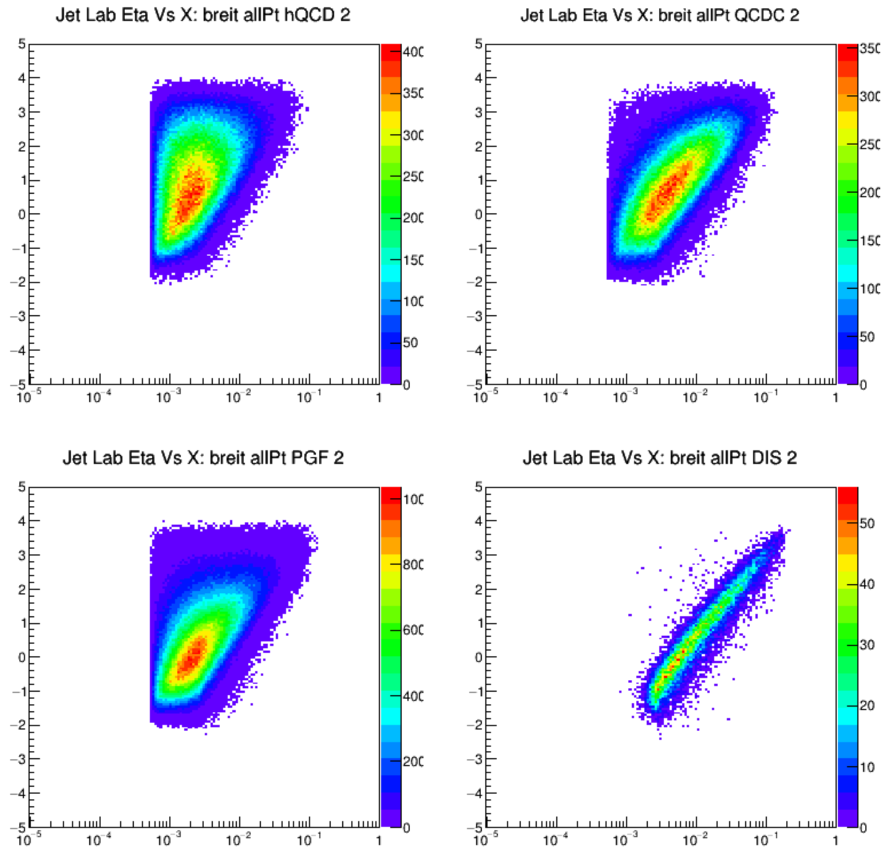
Hadronic calorimetry for EIC

- Hadronic energy resolution, especially in the forward endcap, is important for several EIC physics measurements

- Requirements:
  - Compactness
  - Immunity to the magnetic field
  - High (enough) energy resolution
  - Reasonable cost
  - Other (minimal neutron flux, etc)

- Pending questions:
  - Should one stick to the compensated calorimeter design (which by the way never showed high energy resolution for jets) or consider other options (dual-readout or dual-gate concepts, high-granularity calorimetry)?
  - How at all one can get a decent performance out of a 5-7λ deep HCal?

Jet kinematics for various MC processes

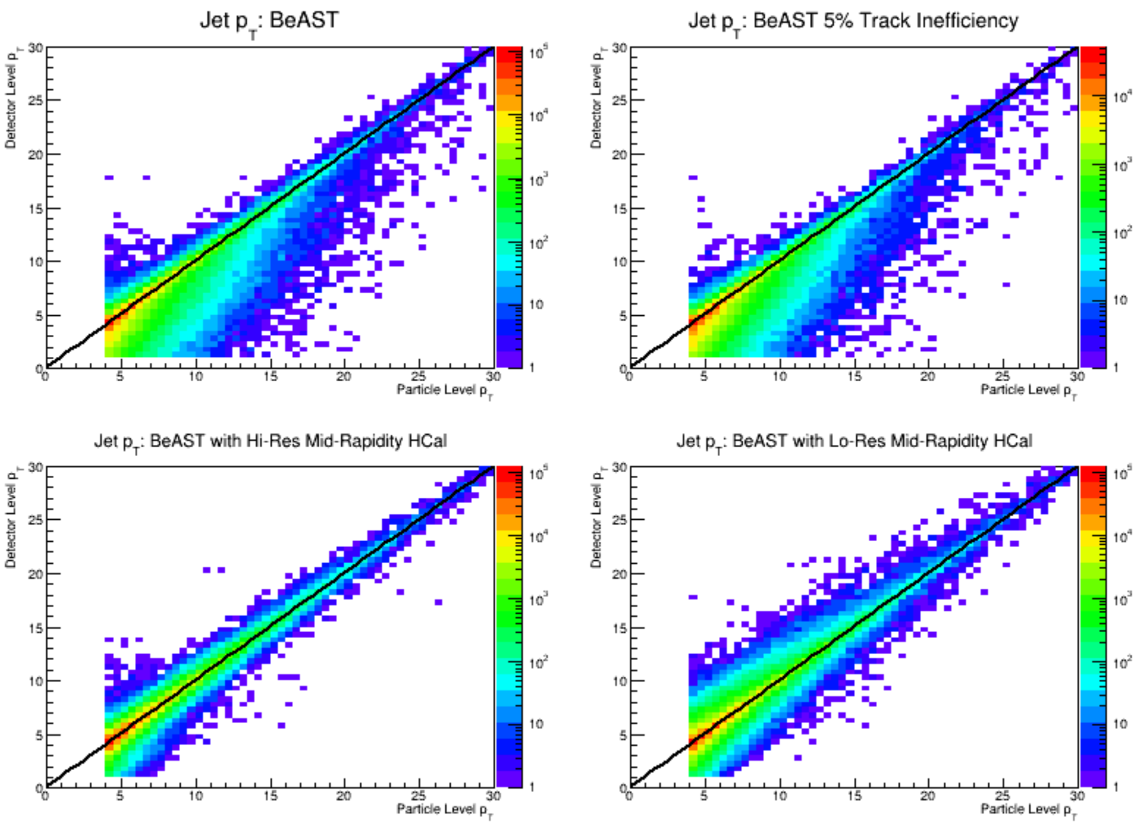


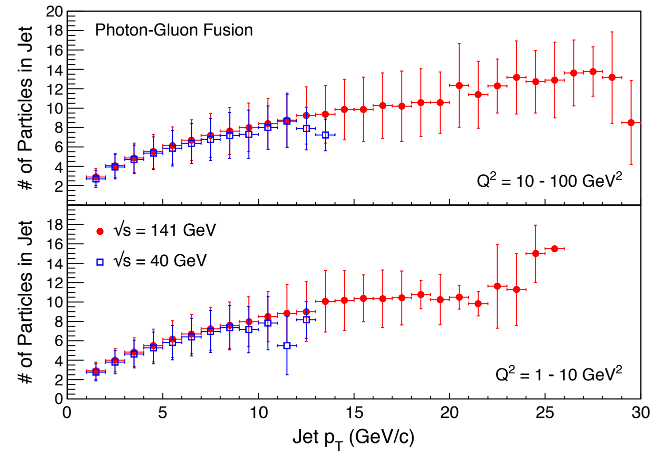
Plots provided by Brian Page

Hadronic calorimeter in the barrel

Jet study for BeAST: ep-events, 20 x 250 GeV, $10 < Q^2 < 100$ GeV^2

- eic-smear pass in a PFA-like fashion (check P_t reconstruction quality)



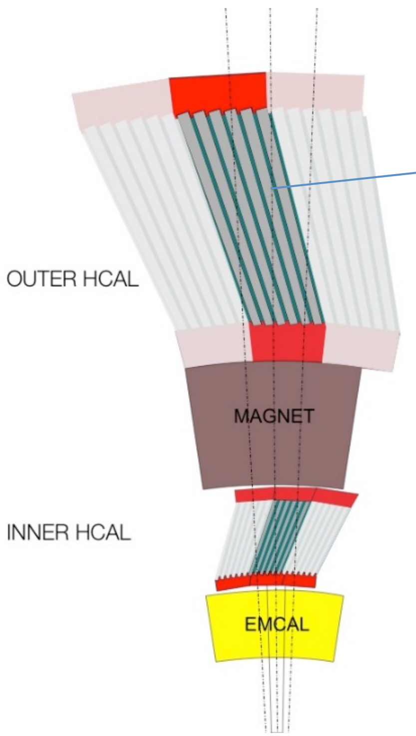


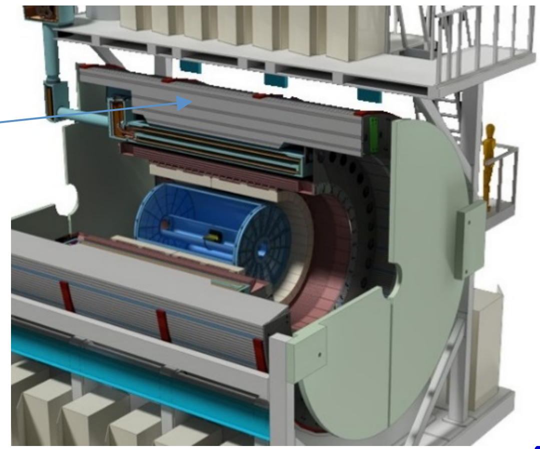
Plots provided by Brian Page

- Here Hi-Res HCal is ~35%/√E + 2% (ZEUS) ...
- ... and Lo-Res HCal is ~85%/√E + 7% (CMS)

-> So it does make a difference

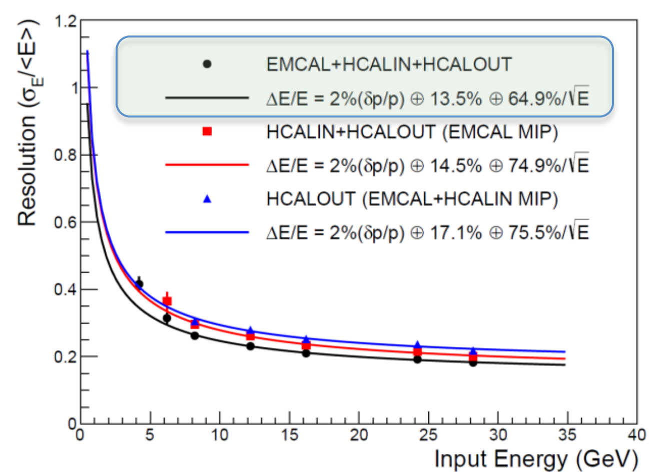
sPHENIX Hadron Calorimeter





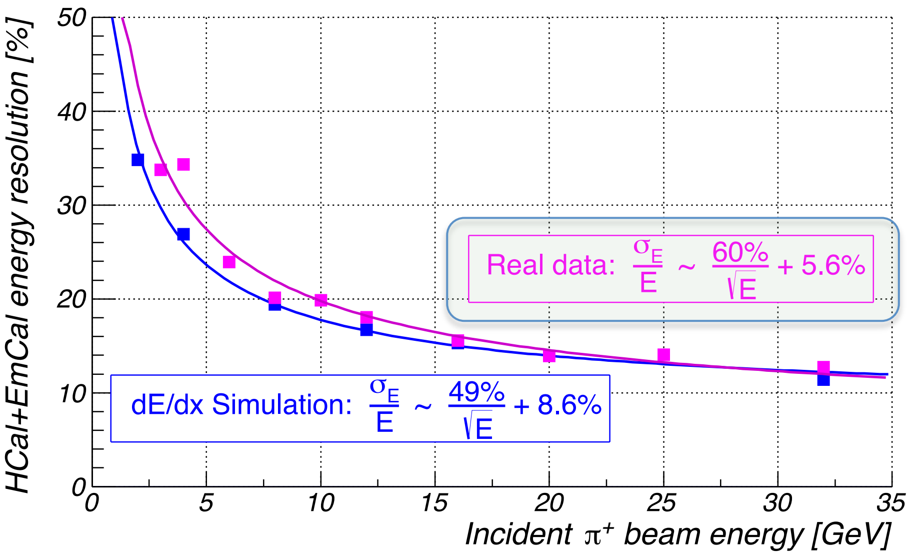
- HCAL steel and scintillating tiles with wavelength shifting fiber
  - **Outer HCal (outside the solenoid)**
  - **$\Delta\eta \times \Delta\varphi \approx 0.1 \times 0.1$**
  - **1,536 readout channels**
- SiPM Readout
- Uniform fiducial acceptance $-1<\eta<1$ and $0<\varphi<2\pi$; extended coverage $-1.1<\eta<1.1$ to account for jet cone

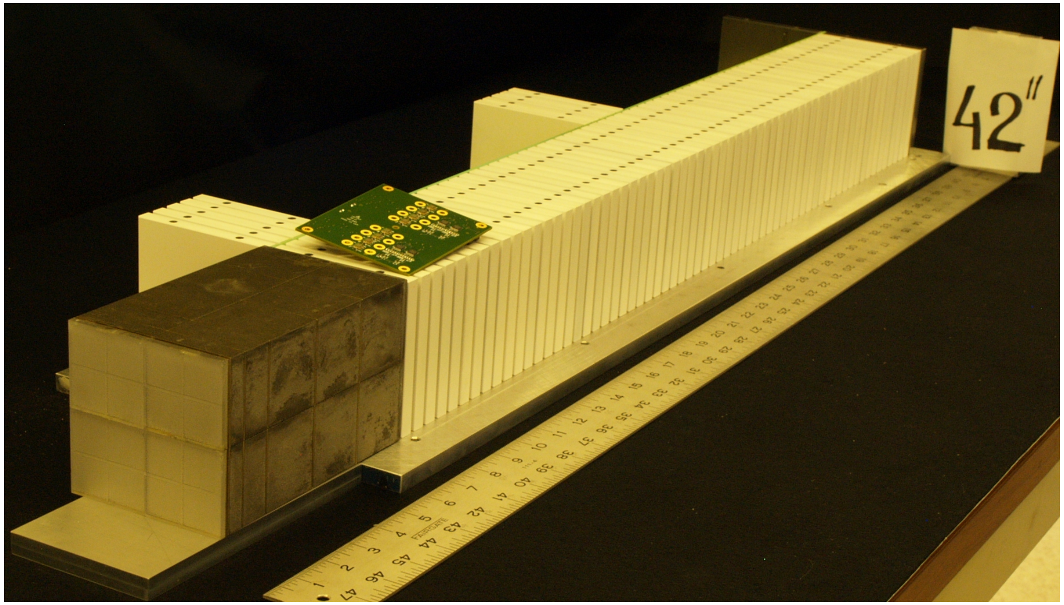
- Outer HCAL $\approx 3.5\lambda_I$
- Magnet $\approx 1.4X_0$
- Frame $\approx 0.25\lambda_I$
- EMCAL $\approx 18X_0 \approx 0.7\lambda_I$

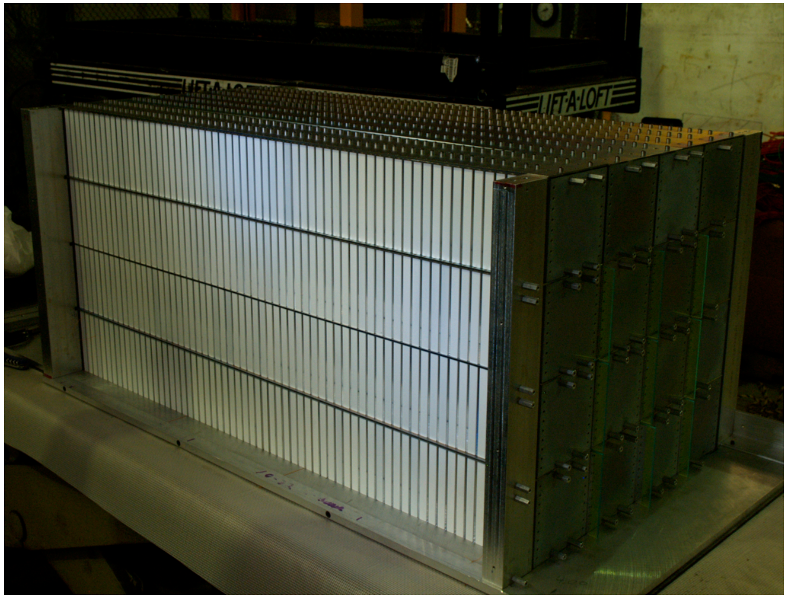


Pb/SciTile EIC calorimeter R&D: early days

- Scintillating tiles interleaved with Pb plates (compensated)
- WLS
- SiPM readout
- Achieve ~60%/√E energy resolution, with ~6% constant term







Dual readout hadronic calorimetry?

The idea:

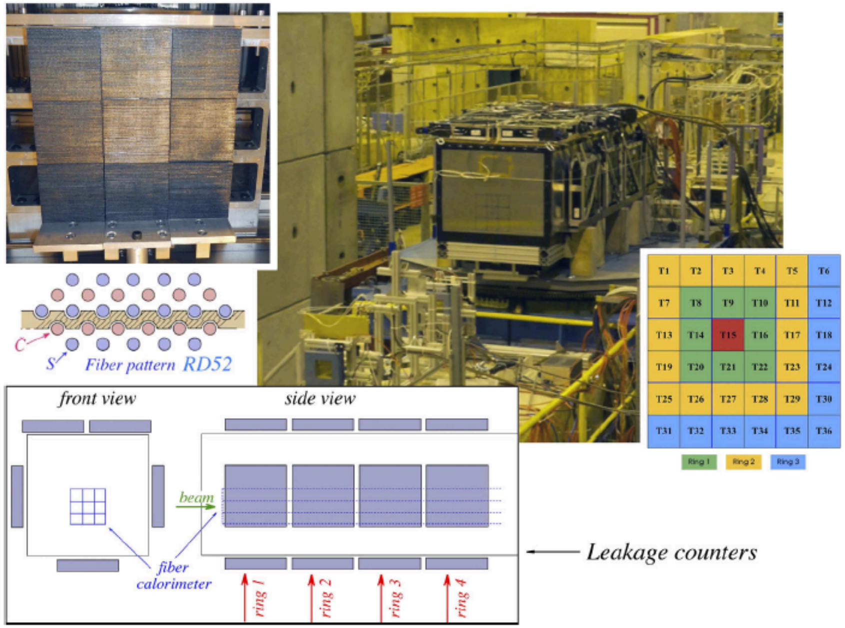
- Abandon built-in compensation (and raise sampling fraction)
- Use two types of fibers as active media (scintillating and clear ones)
- Measure Cherenkov light in addition to the scintillation one and use the ratio of two to correct for the f_{em} fluctuations on event-by-event basis

Performance attained so far:

- DREAM (Cu/fiber): ~65%/√E + 0.6%
- RD52 (Pb/fiber): ~70%/√E

Applicability at EIC is problematic:

- Cumbersome construction process
- So far only a PMT configuration (although a small prototype with SiPMs was tried out already)



Dual-gate hadronic calorimetry?

- Large fluctuations in ‘invisible’ energy (nuclear binding energy) main cause of poor resolution
- Main mechanism of production of **n** is spallation (except for U), can be thought as evaporating nucleons from excited nuclei
- Kinetic energy of **n** correlated with ‘invisible’ energy

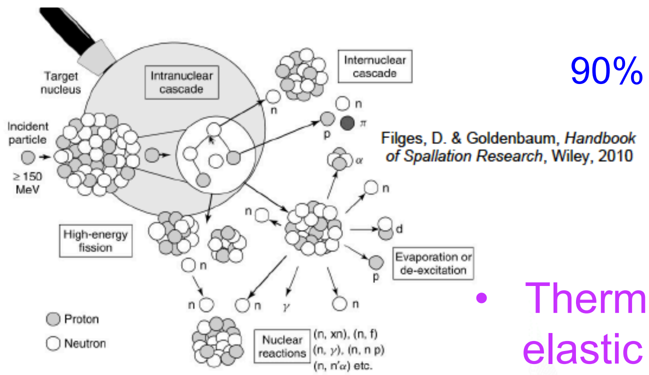
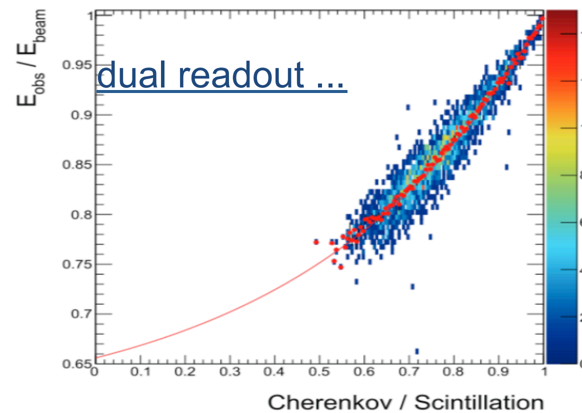
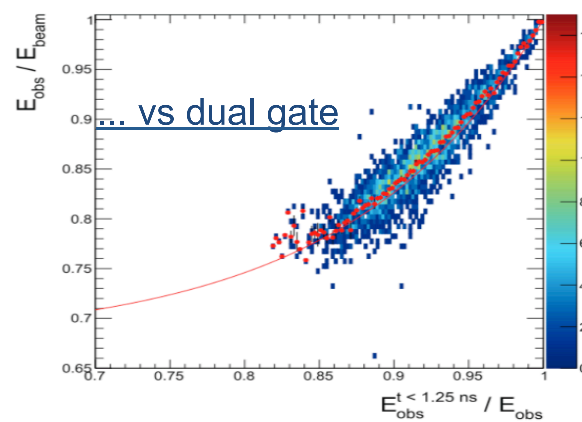


Fig. 1.12 The principal scheme of spallation.

90% between 0.1 and 10 MeV

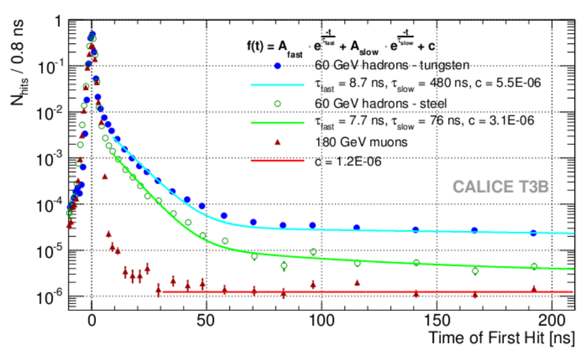


- Thermalization is mainly due to elastic scattering on hydrogen
- Mean free path ~ 20 cm, t ~ 15ns



First measurements by ZEUS in the 90-th; Recently repeated by

- DREAM
- RD52 Collaboration
- CALICE Collaboration

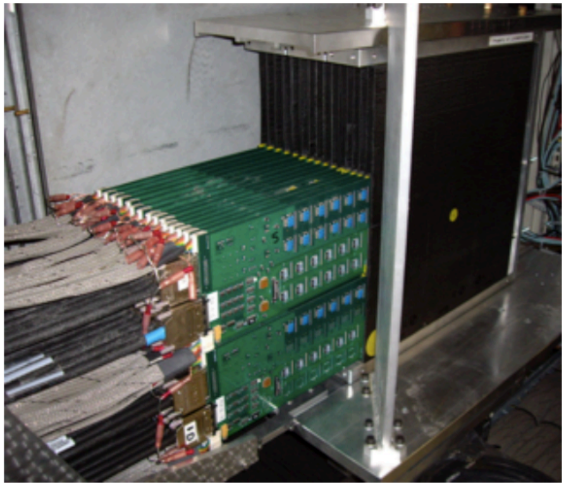


CALICE (Fe/Sc; ~8ns fall-down)

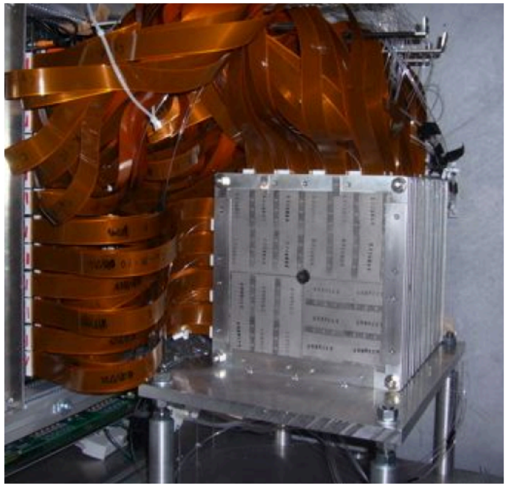
High granularity calorimetry?

-> active community; rapidly developing field; large-scale prototypes

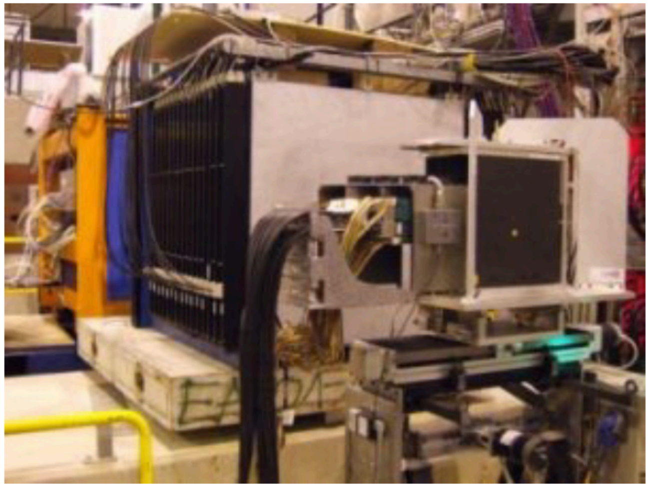
SiW ECAL



ScintW ECAL

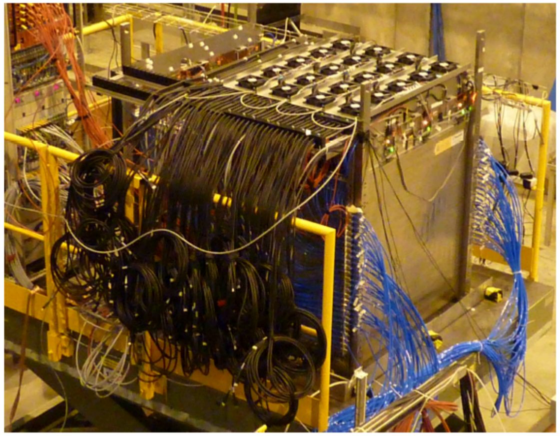


Scint AHCAL, Fe & W



RPC DHCAL, Fe & W

RPC SDHCAL, Fe



plus tests with small numbers of layers:

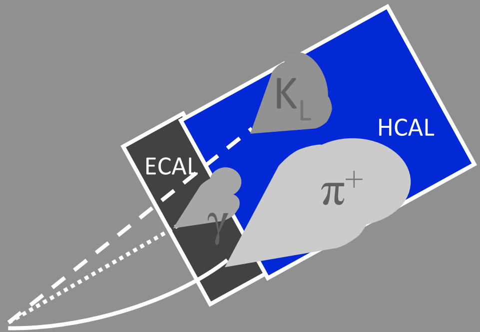
- ECAL, AHCAL with integrated electronics

- Micromegas and GEMs

F.Sefkow, CALOR 2018

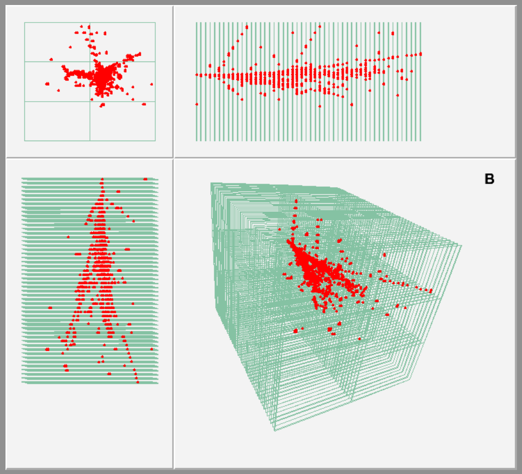
High granularity calorimetry & PFA

Attempt to measure the energy/momentum of each particle in a hadronic jet with the detector subsystem providing the best resolution



The idea

Replace the traditional tower structure with very fine granularity (lateral and longitudinally)
Few 1,000 channels → few 10,000,000 channels
Option to reduce resolution on single channels to 1 – 2 bits (digital readout)



Particles in jets	**Fraction of energy**	**Measured with**	**Resolution** [σ^2]
Charged	65 %	Tracker	Negligible
Photons	25 %	ECAL with 15%/√E	0.07^2 E_{jet}
Neutral Hadrons	10 %	ECAL + HCAL with 50%/√E	0.16^2 E_{jet}
Confusion	If goal is to achieve a resolution of 30%/√E →		**≤ 0.24^2 E_{jet}**

18%/√E

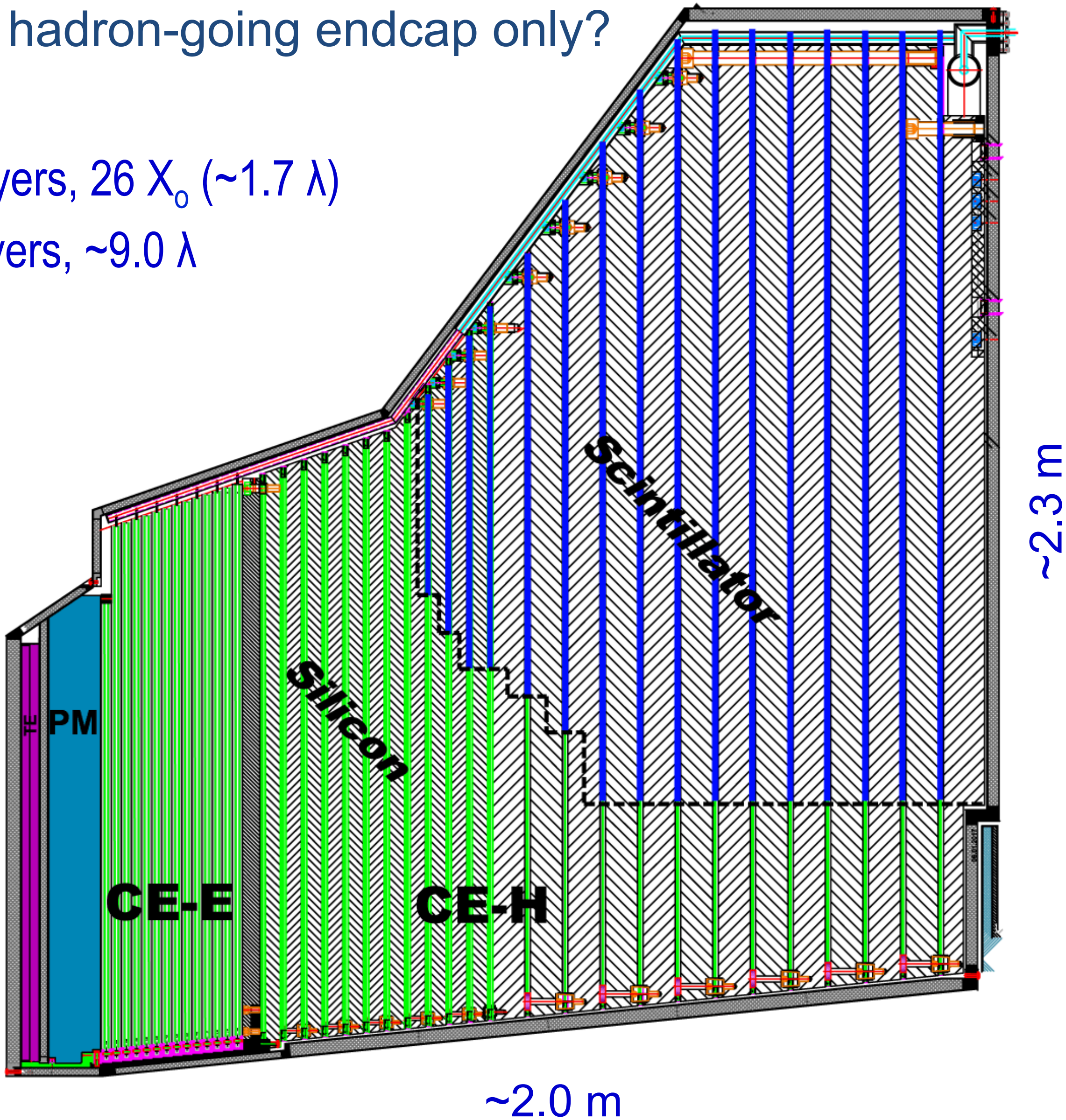
Factor ~2 better jet energy resolution than previously achieved
EIC environment: particularly suited for PFAs, due to low particle multiplicity and low momenta

Based on: J.Repond, 02/08/19 CFNS seminar

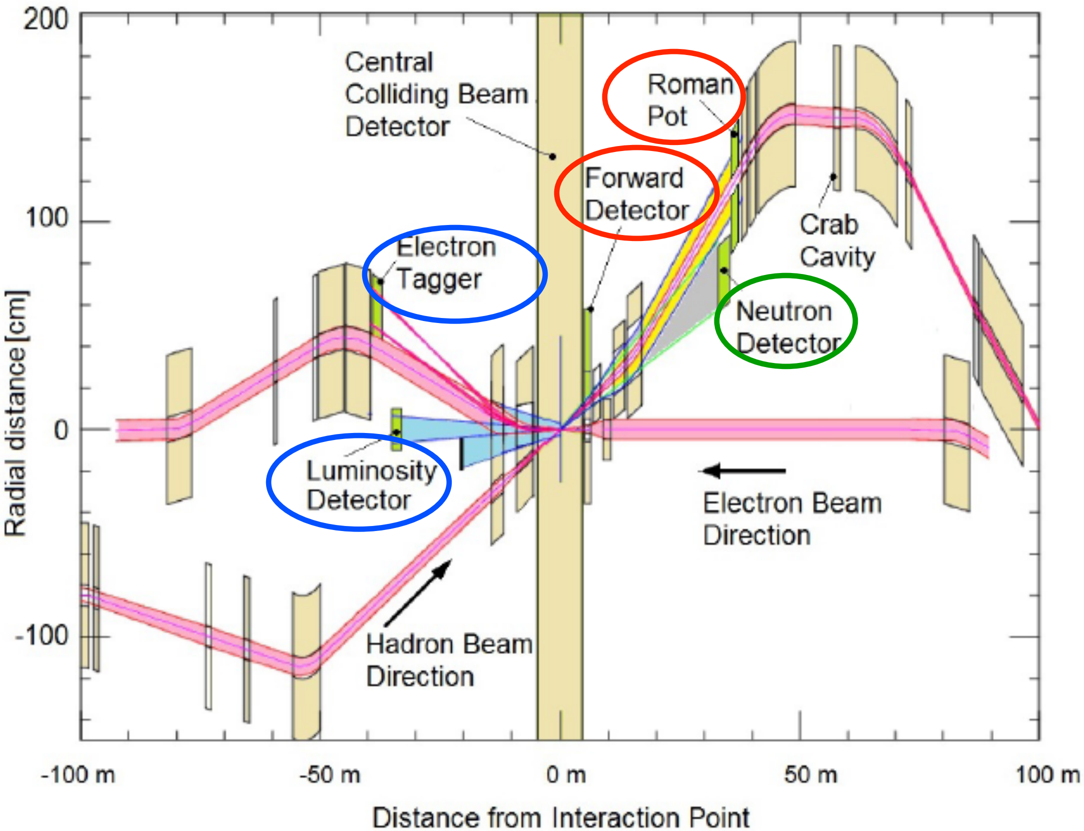
CMS forward calorimeter upgrade

- Use this technology in the hadron-going endcap only?
  - **CE-E**: Si and Cu/CuW/Pb, 28 layers, 26 X_o (~1.7 λ)
  - **CE-H**: Si+Scint and Steel, 24 layers, ~9.0 λ
  - 1.5 < η < 3.0
  - ~600 m^2 of Si,
  - ~500 m^2 of scintillator
  - ~6M Si channels

-> this would be pretty much the size of the EIC "ideal" endcap calorimeter!

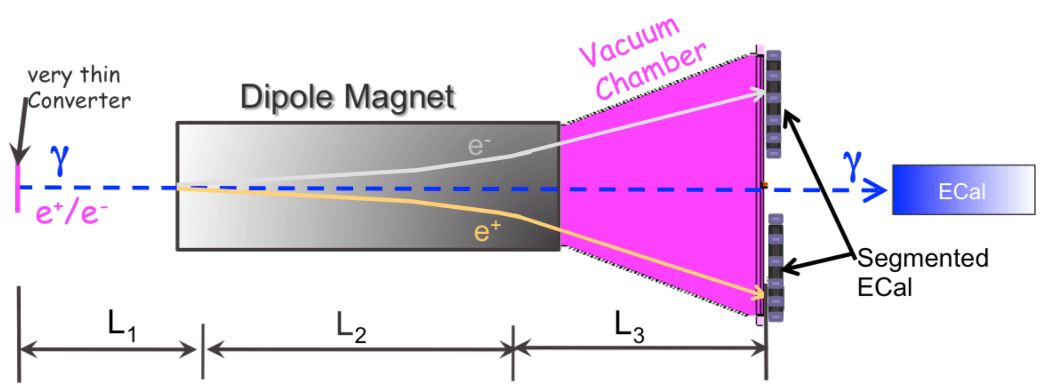


Auxiliary detector calorimeters



- Radiation hardness (both against neutrons and ionizing radiation)
- Highest possible levels of performance (small systems, can be unique)

- Electromagnetic calorimeters
  - Luminosity monitor
  - Low Q^2 tagger
- Hadronic calorimeters
  - Zero-Degree Calorimeter

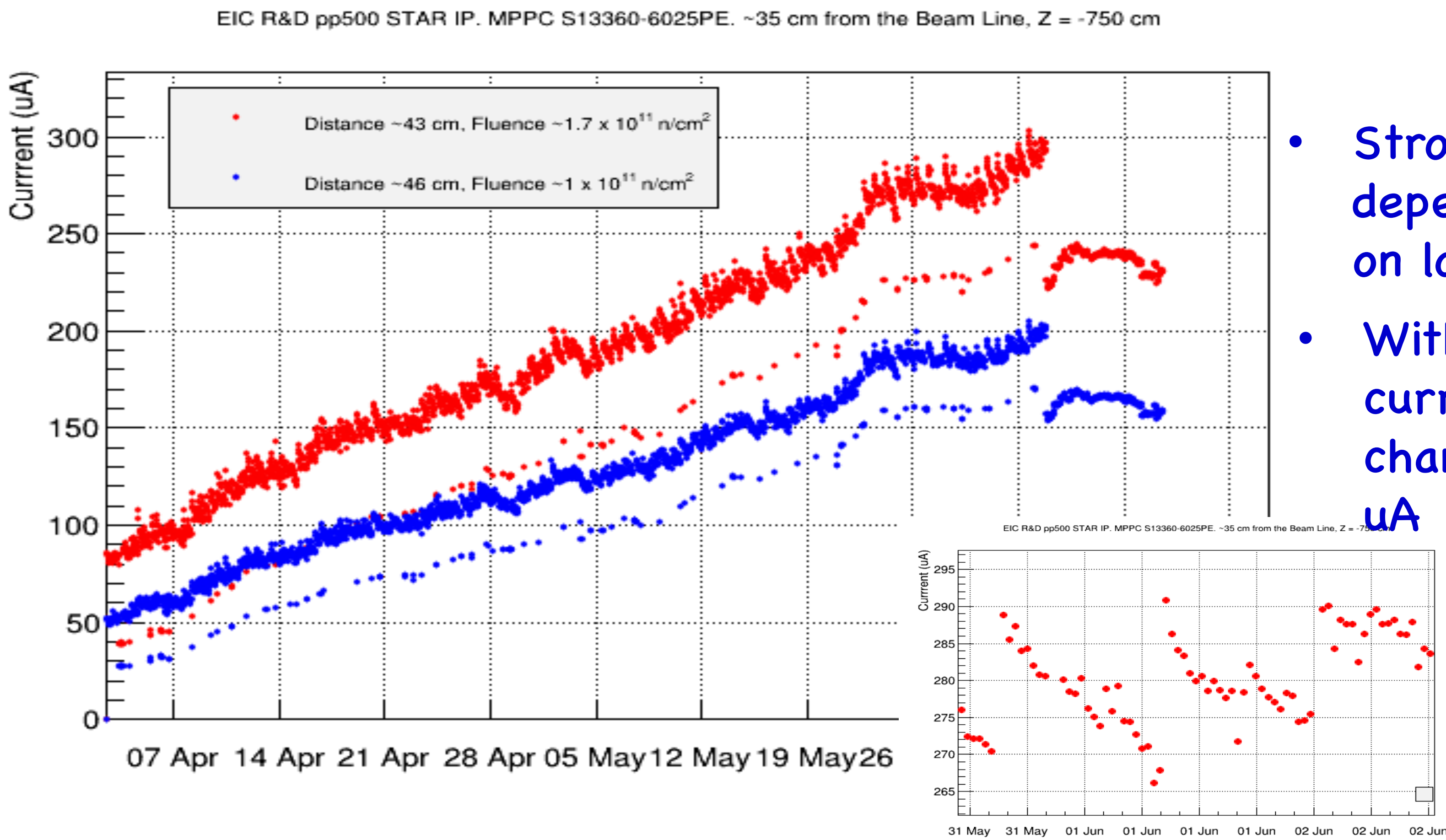


Luminosity monitor a la ZEUS

SiPM radiation damage studies

Radiation damage to SiPMs at STAR

- Run 17. Conditions at STAR Forward close to what will be at EIC.



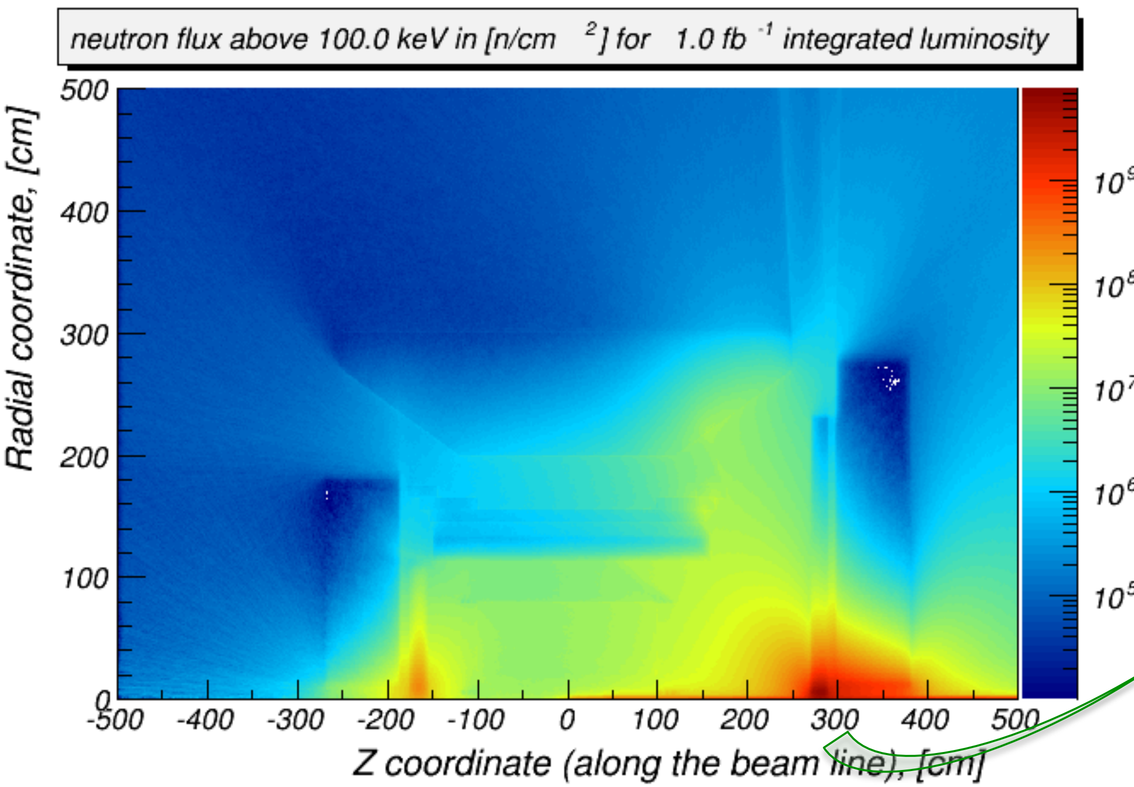
- Strong dependence on location
- Within one fill current changes ~ 35 uA

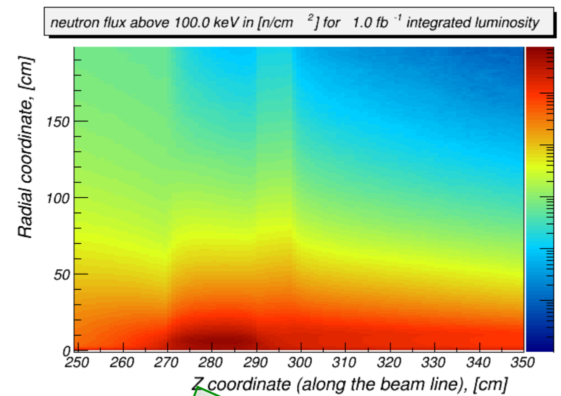
- These are for 36 mm² SiPMs. For 3 x3 mm current will be about 100 uA at the end of the run.
- Gain was set ~ 3×10^5, Overvoltage 2.14V

Backgrounds: neutron fluence

<u>The quantity</u>: Fluence = "a sum of neutron path lengths"/"cell volume" for N events

-> basically use Y.Fisyak's approach for STAR





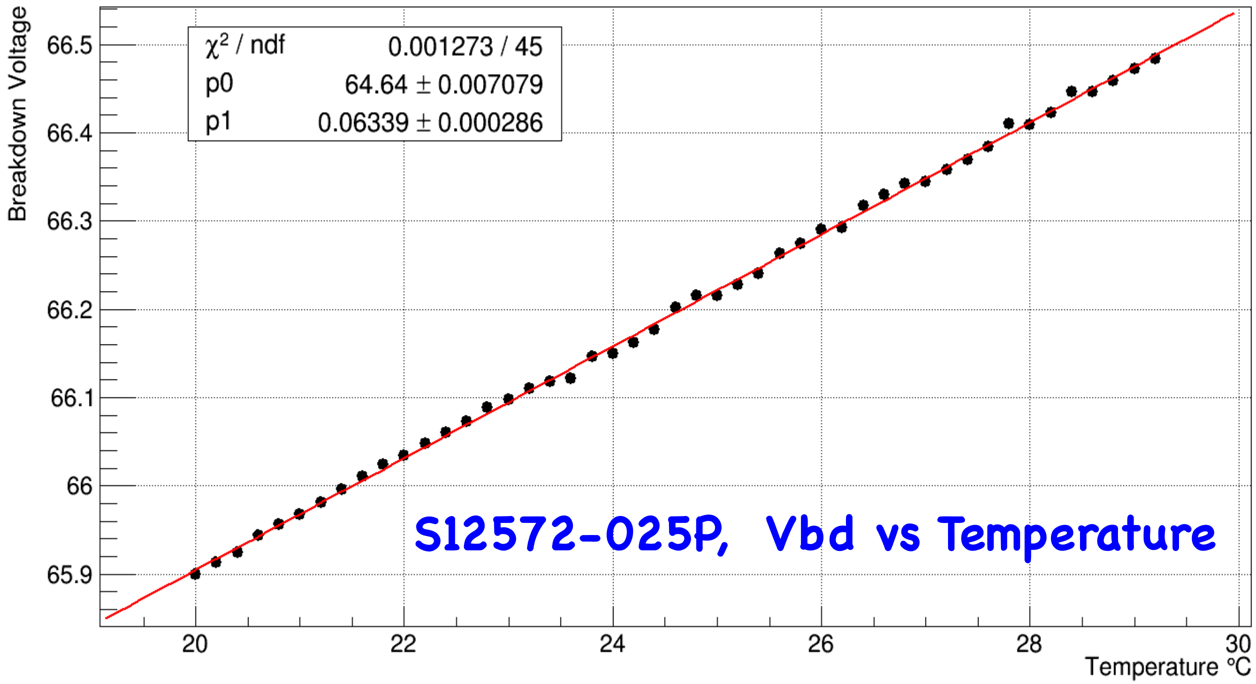
-> forward EmCal: up to ~$5 \cdot 10^9$ n/cm^2 per fb^{-1} (*inside the towers*); perhaps ~5 less at the SiPM location;

NB: "standard" EIC run at ~10^{33} cm^{-2}s^{-1} luminosity is 10 fb^{-1}

- Assume azimuthally-symmetric setup -> so build {R,Z} map

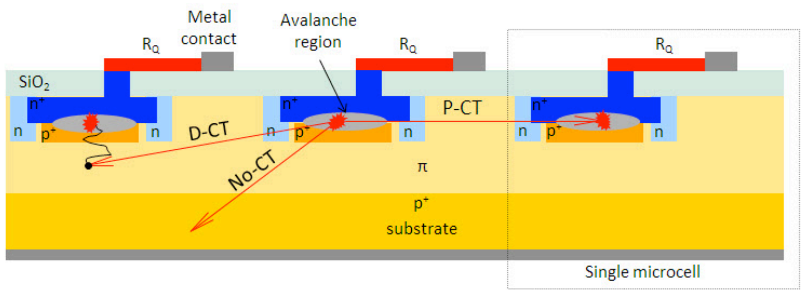
Radiation damage to SiPMs at STAR

Degradation of response due to the shift in Vbd was observed.
Search in literature did not provide clear clues.



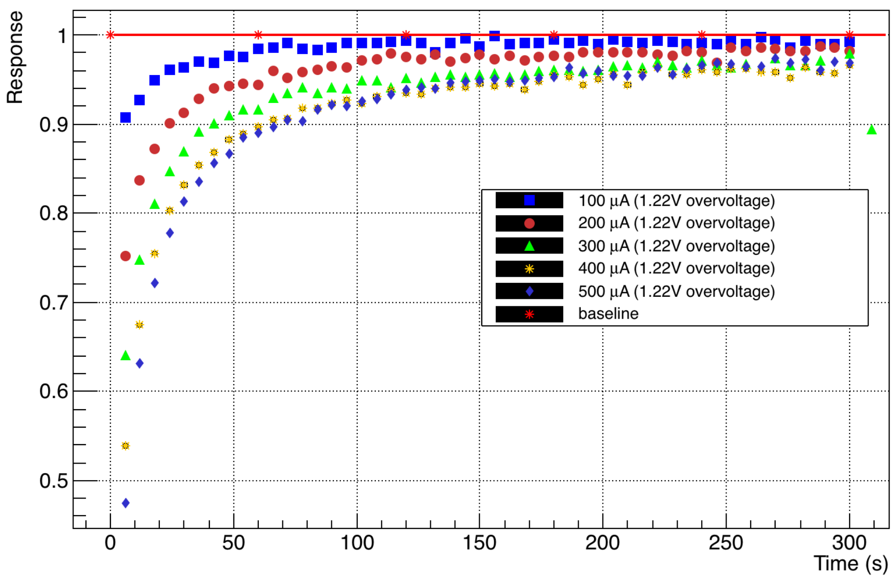
- Vbd changes
- ~ 60 mV/C
- As measured in T controlled chamber in 2017
- (slow heating, 8 hours data taking)

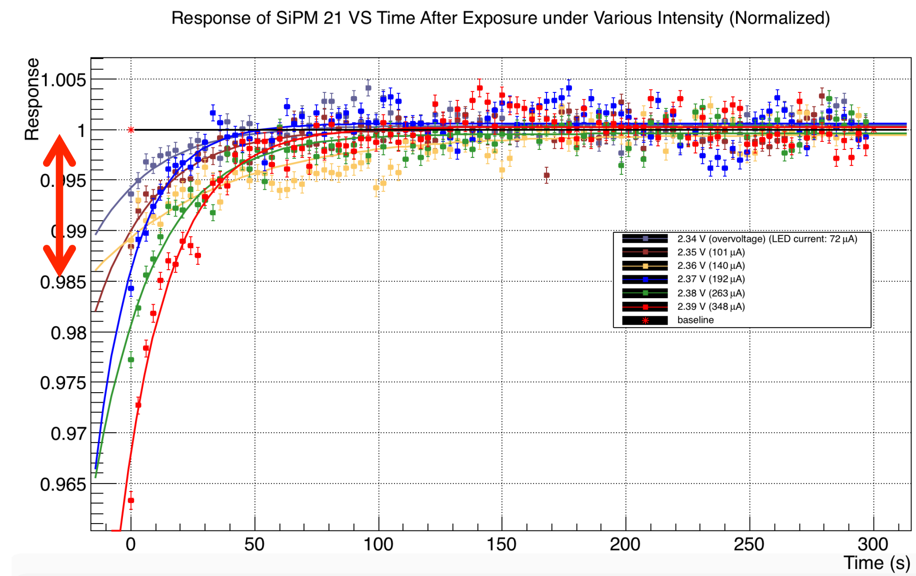
Tricky question
"What T is it?



Radiation damage to SiPMs at STAR

- One approach: measure response. Preheat with LED, switch LED Off, measure response with very low intensity laser





- HPK S13360-06025
- New HPK sensors, HDR2-3x3mm-15um

- Much better performance of the new SiPMs
- Changes in response due to irradiation relative to EIC forward will be within 1%

Radiation damage to SiPMs at STAR

Conclusions

SiPMs un-pleasant properties:

a) Response degrades with increased current flowing through SiPM (dark noise due to rad damages + from primary interaction (light from calorimeter), which heats junction). Expect up to 10% change for EIC Forward.
b) It may be large variations across forward calorimeter surface.
c) Possibly, each SiPM will degrade differently.

T compensation in Vbias does not handle this!

T on junction depends on current, which depends on

- location
- luminosity time profile
- integrated exposure
- ambient temperature
- overvoltage SiPM operates at

Radiation damage to SiPMs at STAR

Summary

Effects of degradation of SiPMs observed during Run17 have been understood:

- Combination of leakage current (due to radiation damages) and signal current from calorimeter light heats junction of the sensors, which leads to increase in Vbd, which leads to degradation of response.

- Differential degradation (variation from sensors to sensors) probably is due to different overvoltage required to achieve same response.

- New HPK sensors are superior to previous versions. Degradation of response for these sensors due to irradiation at forward rapidities at EIC will be very small (~1% level) for Forward Calorimeter.

Summary

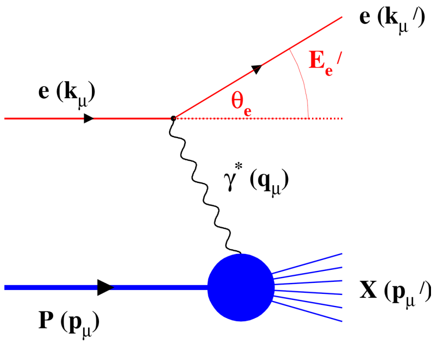
- EIC Calorimeter Consortium within the Detector R&D program is an active community working on several exciting projects
- Some of the technological solutions are being already used in other experiments:
  - sPHENIX EmCal
  - STAR forward upgrade HCal
- Further refinement of the detector specifications driven by physics is required
- We believe we should be able to provide the solutions for all the EIC detector calorimetry subsystems in time

Backup

Experimental measurements

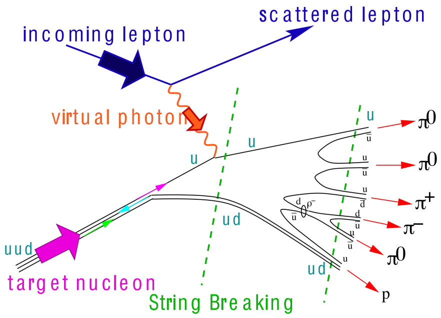
Inclusive Reactions in ep/eA:

- Physics: Structure Functions: g_1, F_2, F_L
- → Very good scattered electron ID
- → High energy and angular resolution of e' (kinematics $\{x, Q^2\}$)



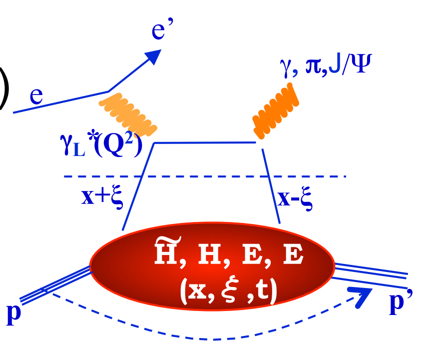
Semi-inclusive Reactions in ep/eA:

- Physics: TMDs, Helicity PDFs, FFs (with flavor separation); di-hadron correlations; Kaon asymmetries, cross sections; etc
- → Excellent hadron ID: $p^{\pm}$,$K^{\pm}$,$p^{\pm}$ separation over a wide $\{p, \eta\}$ range
- → Full Φ-coverage around γ^*, wide p_t coverage (TMDs)
- → Excellent vertex resolution (Charm, Bottom separation)



Exclusive Reactions in ep/eA:

- Physics: DVCS, exclusive VM production (GPDs; parton imaging in b_T)
- → Exclusivity (large rapidity coverage; reconstruction of all particles in a given event)
- → High resolution, wide coverage in t → Roman pots
- → (eA): veto nucleus breakup, determine impact parameter
- → Sufficient acceptance for neutrons in ZDC



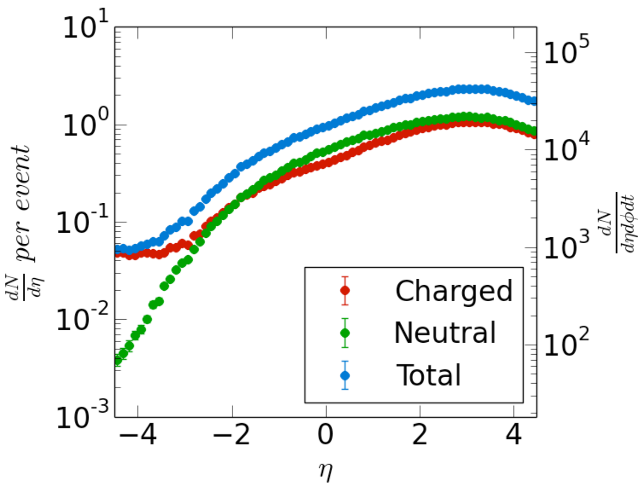
Crystal EmCal decay time

The requirement since ever was **fast (few dozens of ns)**

... which may well be fine, but:

- With the original eRHIC machine design (~100ns bunch crossing frequency) it was to some extent motivated by desire to avoid “per definition” event overlap from neighboring bunches

With ~500kHz interaction rate at 10^{34} cm^{-2} sec^{-1}, ~1 particle per unit of η in an “average” ep-event and clear intention to use high frequency sampling electronics in a streaming readout environment one may well want to re-consider this:



- Back-of-the-envelope numbers for the BeAST barrel: one unit of η is ~100 x 600 cm^2 surface, 3x3 cluster for towers matching Moliere radius of say CsI(Tl) is ~10 x 10 cm^2 -> 1:500 or so
- on average ~2μs between events
- same order, few μs “integration time” (CsI(Tl): ~960ns decay time; BaF_2: ~650ns)

-> it does not look event overlap is likely, or?

Other "requirements", in passing

"Best possible ZDC neutron energy resolution needed for eA centrality selection"

- What about Fermi motion?

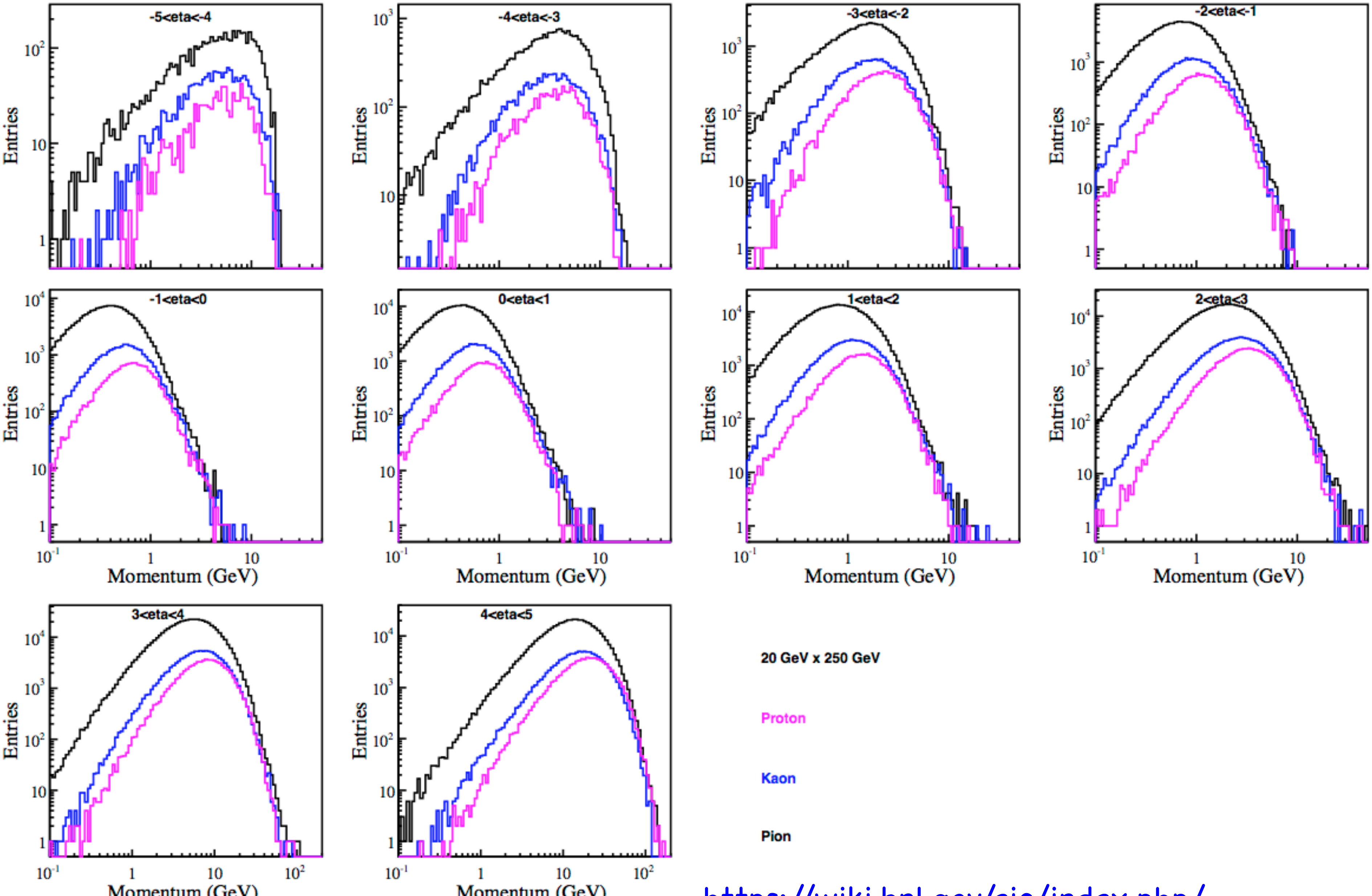
"Hermetic EmCal and HCal coverage up to $|\eta| \sim 4$"

- $\eta=4$ is $\sim 2^0$, so ~30 mrad -> how about 1) crossing-angle, 2) hadron-going direction "stay clear" cone of >20mrad, 3) electron-going direction synchrotron fan opening and 4) fiducial volume area close to the beam pipe in general (no shower containment)?

"Exclusivity requirement on the level of ~100 MeV"

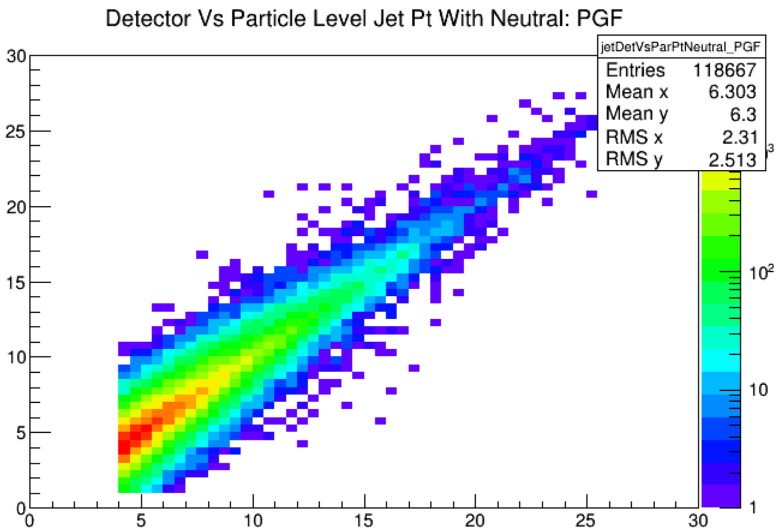
- What about beam energy spread? eRHIC: ~6E-4 @ 275 GeV

Conditions. Energy range.

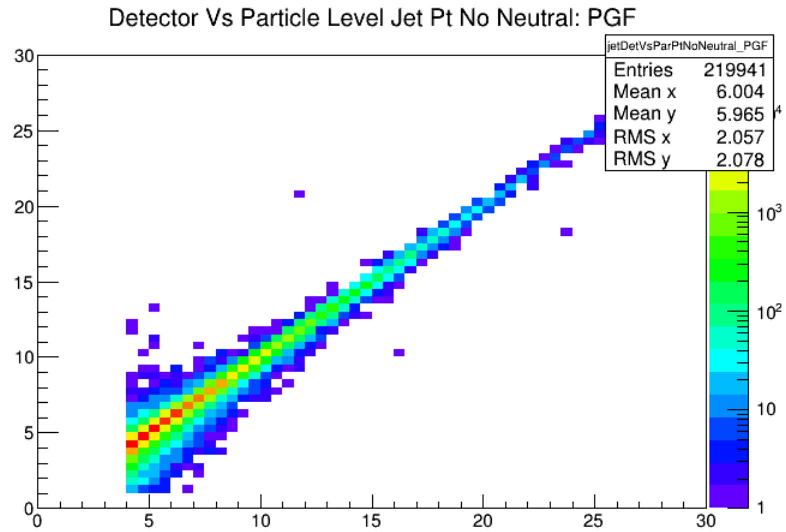


https://wiki.bnl.gov/eic/index.php/Detector_Design_Requirements

Hadronic calorimeter in the barrel



Jets with neutral particles



Jets without neutral particles

-> So can use even poor resolution HCal to identify ~1/3 of jets, which contained neutrals (and perhaps just veto them in analysis)

Anyway: is mid-rapidity HCal *absence* of any good?

"Classic" sampling calorimeters

The best ones are in the past:

- Pb/Sc.fibers (SPACAL) -> ~30%/√E
- U/Sc.plates (ZEUS) -> ~35%/√E

The recipe is known:

- Suppress "invisible energy" fluctuations by built-in compensation
- Maintain sufficient sampling frequency

Present calorimeters (take LHC ones):

- ATLAS: *design* resolution ~50%/√E + 3.0%
- CMS: *design* resolution ~100%/√E + 4.5%

Backgrounds: neutron fluence

So far the plot from the previous slide is the only modeling source of information used to question SiPM readout (integrated flux is too high)

The numbers look reasonable, but:

- These are the rates **from primary interaction only**
- Beam line elements not incorporated in the simulation
- A particular detector geometry used (BeAST)

- GEANT3 used; a comparison against GEANT4 has never been done

- Thermal neutrons are not accounted
- In fact the integrated neutron flux is high only close to the beam pipe ...
- ... and the new generation Hamamatsu SiPMs show much higher neutron fluence resistance